Understanding the decision-making process in homeowner energy retrofits
From behavioural and transaction cost perspectives

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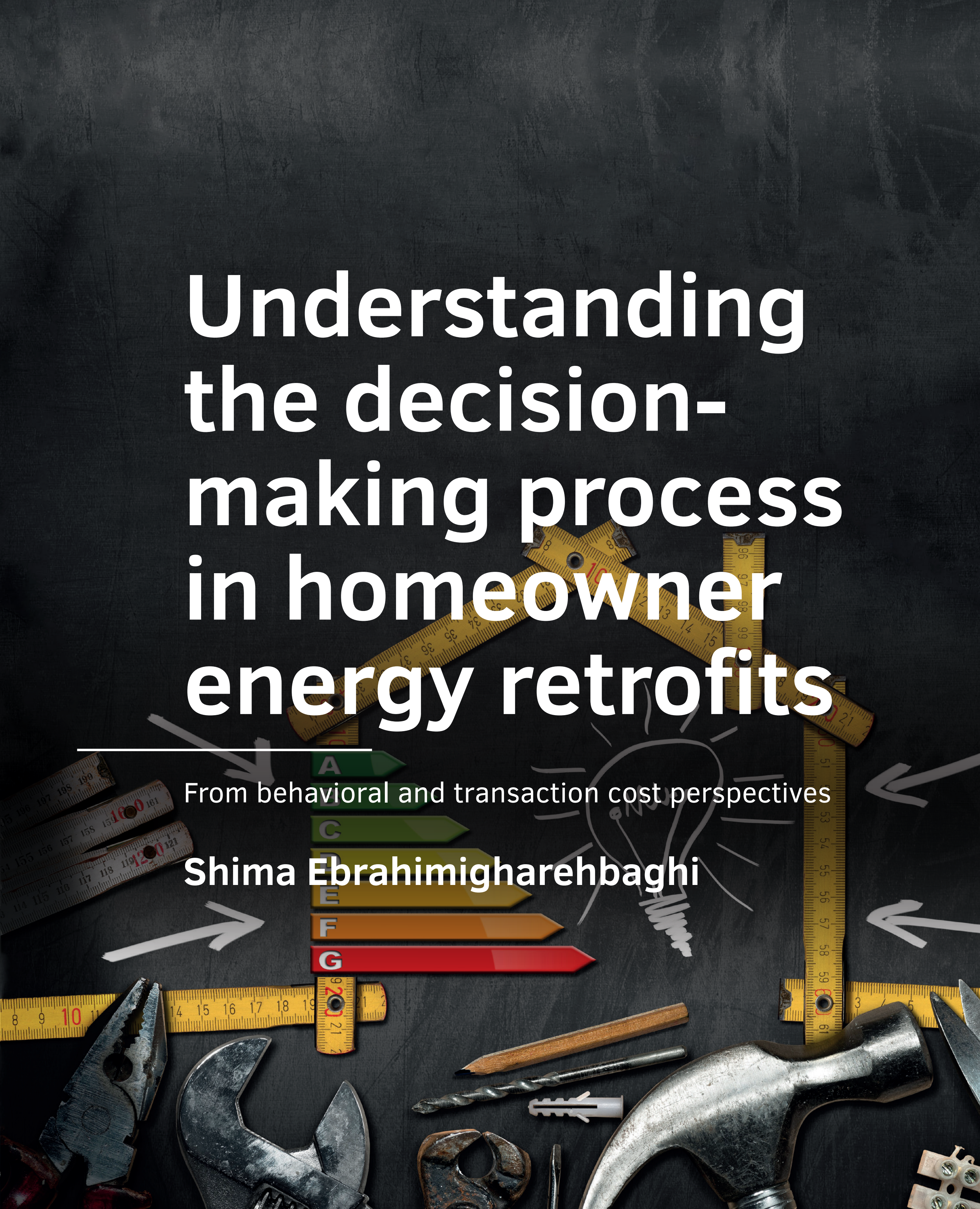

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Understanding the decision-making process in homeowner energy retrofits

From behavioral and transaction cost perspectives

Dissertation

for the purpose of obtaining the degree of doctor
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by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen
chair of the Board for Doctorates
to be defended publicly on
9 May 2022 at 12:30 o'clock

by

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This dissertation has been approved by the promotors.

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Dedicated to my beloved parents

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Summary

Energy retrofitting of residential buildings can significantly reduce the vast global CO_2 emissions from the building sector. Retrofitting has the advantage of producing much lower CO_2 emissions than demolishing and building new energy-efficient homes; however, despite its potential, the retrofitting rate in the residential sector in the Netherlands remains very low. It is potentially challenging for homeowners to collect information, make decisions, find funding sources, and monitor or install energy retrofits. Similarly, for policymakers, convincing homeowners to retrofit their homes solely for energy savings is also difficult to achieve [112, 393, 478]. To facilitate increased uptake of energy retrofits, it is necessary to investigate the factors that influence decision-making behaviour and hinder the retrofit process. Based on such an investigation, targeted incentives can be recommended to promote energy retrofitting and remove barriers that impede the process.

The knowledge gap that this dissertation aims to address is as follows — while current literature focuses on examining the key financial and technical barriers to accelerating energy retrofits, little attention has been paid to the factors that influence behaviour and non-monetary hidden costs, i.e., transaction cost barriers during the retrofit process. This dissertation aims to assess (a) the main factors influencing behaviour, including psychological factors, during the decision-making process of homeowners regarding energy retrofits [183, 451, 480] and (b) the transaction cost barriers, i.e., the non-monetary costs or hidden costs, during the retrofit process [113, 135, 313, 316].

This work's main innovative contributions are (a) development of a comprehensive framework encompassing the key factors that influence the decision-making and renovation process and (b) investigation of the impact of psychological factors, particularly cognitive biases, on the renovation decision-making process. The main data sources used are the 2012 and 2018 national surveys on energy modules, the 2012 survey by the research institute for the built environment (OTB), semi-structured interviews and focus group meetings. The quantitative data are processed using statistical modelling techniques and logistic regression analyses to explore the effects of factors that influence behaviour and transaction cost barriers. For the first time, two mathematical models that assume rational and irrational decision-makers, are investigated to examine the effects of cognitive biases during the energy retrofit decision-making process.

This dissertation consists of four sections, each designed to examine different categories of factors influencing behaviour and transaction cost barriers for different renovation types. The first section examines the combined effects of behaviour-influencing factors and transaction cost barriers during the decision-making and energy retrofit process. Based on a literature review, an integrated framework of behaviour-influencing factors and transaction cost barriers in the decision-making and energy retrofit process is developed. The theoretical framework is validated by performing statistical and regression analyses on data from the 2012 energy module survey. Based on this analysis, behavioural influencing factors and transaction cost barriers together can explain the entire process of decision making and energy retrofitting. Moreover, behaviour-influencing factors and transaction cost barriers are particularly important in the early (before final decision making) and later (final decision making and implementation) stages of the retrofit process, respectively. Among the different categories of behaviour-influencing factors, building and household characteristics rank first and second, respectively; in addition, quality of life improvement and financial benefits are cited as the most important motivating factors. Transaction cost barriers include information acquisition, negotiation, and monitoring costs. These barriers prolong the energy retrofit process [313, 316, 345] and represent the second most important category of barriers after financial barriers.

To further investigate the impact of different categories of behaviour-influencing factors, the second section of this work examines the impact of psychological factors on different energy retrofit types based on a literature review and regression analyses of the 2018 energy module survey. Psychological factors were found to be of highly significant importance in retrofitting. The decision to install a sustainable heating system is strongly dependent on households' awareness of their gas consumption, while households' perceptions of their energy consumption compared to others strongly influence the decision to install PV panels. In addition, motivational factors vary depending on the type of energy retrofit; for example, the installation of a PV system depends on the household's motivation to achieve energy cost savings and protect the environment.

In the second section, an investigation was also undertaken as to whether accounting for cognitive biases improves the prediction of actual energy retrofit decisions. For this purpose, the classical expected utility theory (EUT) is compared with the cumulative prospect theory (CPT), the latter incorporating cognitive biases [183, 258, 451]. The main data for these analyses are obtained from the 2012 and 2018 energy module surveys. The results confirm CPT's better predictive ability of decision behaviour relative to the EUT approach. Moreover, households that generally avoid risks and losses were found to be more likely to invest in energy retrofits than others to avoid the potential impact of future losses.

The importance of transaction cost barriers for energy retrofits became clear in the first section of this dissertation; thus, a more detailed investigation of transaction cost barriers for energy retrofits and renovations is conducted in the third section of this work. The 2012 OTB survey formed the basis for these analyses. It was found that (1) the time and effort required to obtain information, (2) the reliability of information and experts, and (3) the complexity of carrying out the energy retrofit are the most important transaction cost barriers for homeowners during the energy retrofit process. In addition, despite huge financial support from the Dutch government, financial issues, such as high retrofitting costs, remain the major barrier to energy retrofits. This specific barrier may, therefore, be related to hidden costs, such as the complexity of applying for loans and grants, lack of household awareness of loan and grant availability, and the uneven distribution of loans and grants among households. Finally, transaction costs also depend on renovation type. Finding reliable contractors and the complexity of carrying out exterior renovations, as well as assessing expenditures for interior renovations, are the main transaction cost barriers for various renovations.

The final section of this dissertation validates the findings of the work through semi-structured interviews and focus group sessions with municipal project managers and practitioners involved in the energy transition. The results of this study are used to identify potential mismatches between current energy policies and homeowners' needs, including: (1) the lack of energy retrofits tailored to the needs of specific building and household groups, (2) the importance of suitable messaging and ambassadors to promote energy retrofits to specific household groups, (3) the insufficient implementation of behavioural interventions and nudges to promote energy retrofits, and (4) the lack of integrated financial, informational, and technical support, especially for homeowners interested in energy retrofits.

Policymakers can use the findings of this dissertation by applying behavioural science insights to promote energy retrofits and help homeowners reduce transaction cost barriers encountered during the retrofit process. Behavioural science insights can be used to tailor solutions to household needs and characteristics. Using the right message (e.g. comfort improvement, maintenance, and cost savings) and the right ambassador (e.g. trustworthiness, shared identity, and expertise) can lead to higher energy retrofit rates. The right message can also involve explaining to risk- and loss-averse individuals the impact of energy retrofits in terms of loss/cost reduction. The lack of a single, integrated point of contact for financial, technical, and informational assistance prolongs the retrofit process, even for homeowners interested in energy retrofits. Removing these transaction cost barriers requires the intervention of a third party or a new agency that connects the various players in the market. To this effect, the concept of ‘one-stop stores’ is already in operation locally and now needs to be developed on a larger scale than only a few cities in the Netherlands. In addition, this new agency could be a digital platform that provides information on various aspects of the process, such as loan and grant availability and suitable types of energy retrofits for different households. Such a platform could also bring together energy retrofit providers and customers, saving both market parties significant time and effort.

Samenvatting

Het aanpassen van bestaande woongebouwen kan de enorme hoeveelheid wereldwijde CO_2 emissies van deze sector aanzienlijk verminderen. Renovatie zelf heeft het voordeel dat het veel lagere CO_2 uitstoot produceert dan het slopen en bouwen van nieuwe energiezuinige woningen. Ondanks het potentieel is het renovatiepercentage in de residentiële sector in Nederland zeer laag. Het kan een uitdagende taak zijn voor huiseigenaren om informatie te verzamelen, hun beslissingen te nemen, financieringsbronnen te vinden en energie-renovatie te controleren of te installeren. Voor beleidsmakers is het overtuigen van huiseigenaren om hun huis alleen voor energiebesparing aan te passen ook ingewikkeld [112, 393, 478]. Om energie-renovatie te vergemakkelijken, is het noodzakelijk om de factoren te onderzoeken die het besluitvormingsgedrag beïnvloeden en retrofitprocessen belemmeren. Als gevolg van dit onderzoek kunnen de nodige stimulansen worden aanbevolen om de barrières tijdens de energierenovatieprocessen te verminderen.

De wetenschappelijke kloof die dit proefschrift aanpakt, is dat de focus van de huidige literatuur lag op het onderzoeken van de belangrijkste financiële en technische barrières voor het versnellen van energie-renovatie, maar er is weinig aandacht besteed aan de factoren die gedrag en niet-monetaire verborgen kosten beïnvloeden, d.w.z. transactiekostenbarrières tijdens het retrofitproces. Dit proefschrift heeft tot doel bij te dragen aan de literatuur door (a) de belangrijkste factoren te onderzoeken die gedrag beïnvloeden, waaronder psychologische factoren, tijdens het besluitvormingsproces van huiseigenaren in energierenovaties [183, 451, 480] en (b) de transactiekostenbarrières, de niet-monetaire kosten of verborgen kosten, tijdens het retrofitproces [113, 135, 313, 316]. Het innovatieve aspect van dit werk was het ontwikkelen van een uitgebreid kader dat de belangrijkste beïnvloedende factoren tijdens het besluitvormings- en renovatieproces omvat, en het onderzoeken van de impact van psychologische factoren, met name cognitieve vertekeningen, op het besluitvormingsproces voor renovatie

De belangrijkste gegevensbronnen die zijn gebruikt de nationale enquêtes over energiemodules, de enquête van het Onderzoeksinstituut voor Huisvesting van de TU Delft, semi-gestructureerde interviews en focusgroepbijeenkomsten. De kwantitatieve gegevens zijn verwerkt met behulp van statistische modellerings-technieken en regressieanalyse om de impact te onderzoeken van factoren die gedrag en transactiekostenbarrières beïnvloeden. Voor het eerst zijn twee wiskundige modellen die uitgaan van rationele en irrationele besluitvormers vergeleken om de effecten van cognitieve vertekeningen tijdens het besluitvormingsproces van energie-renovatie te onderzoeken.

Dit proefschrift bestaat uit vier fasen, elk ontworpen om verschillende categorieën van factoren te onderzoeken die van invloed zijn op gedrags- en transactiekostenbarrières voor verschillende soorten renovatie. De eerste fase van dit proefschrift onderzocht de gecombineerde effecten van gedragsbeïnvloedende factoren en transactiekostenbarrières tijdens het besluitvormings- en energie-renovatieproces. Op basis van het literatuuronderzoek werd een geïntegreerd raamwerk van gedragsbeïnvloedende factoren en transactiekostenbarrières in het besluitvormings- en energie-renovatieproces ontwikkeld. Transactiekostenbarrières omvatten informatie-acquisitie, onderhandeling en monitoringkosten. Transactiekostenbarrières verlengen het energie-renovatieproces [313, 316, 345]. Het theoretisch kader werd gevalideerd door statistische en regressieanalyses op de energiemodule 2012. Het is gebleken dat de gedragsbeïnvloedende factoren en transactie kostenbarrières samen het hele proces van besluitvorming en energie-renovatie kunnen verklaren. Bovendien zijn gedragsbeïnvloedende factoren en transactiekostenbarrières vooral belangrijk in respectievelijk de vroege stadia (vóór de definitieve besluitvorming) en latere stadia (definitieve besluitvorming en implementatie) van het retrofitproces. Van de verschillende categorieën van gedragsbeïnvloedende factoren staan bouw- en huishoudkenmerken respectievelijk op de eerste en tweede plaats. Daarnaast worden verbetering van de kwaliteit van leven en financiële voordelen genoemd als de belangrijkste motiverende factoren. Daarnaast zijn transactiekosten de op één na belangrijkste categorie barrières na financiële barrières.

Om de impact van verschillende categorieën gedragsbeïnvloedende factoren verder te onderzoeken, onderzocht de tweede fase de impact van psychologische factoren op verschillende soorten energie-renovatie met behulp van het literatuuronderzoek en regressieanalyses op de energiemodule 2018. Geconcludeerd wordt dat psychologische factoren van groot belang zijn bij renovatie. De beslissing om een duurzaam verwarmingssysteem te installeren is sterk afhankelijk van het bewustzijn van huishoudens over hun gasverbruik. De perceptie van huishoudens van hun energieverbruik in vergelijking met anderen heeft een sterke invloed op de beslissing om PV-panelen te installeren. Bovendien variëren motiverende factoren afhankelijk van het type energie-renovatie. De installatie van een PV-systeem is afhankelijk van de motivatie om energiekosten te besparen en het milieu te beschermen.

In de tweede fase onderzochten we ook of het verantwoorden van cognitieve vooroordelen de voorspelling van daadwerkelijke beslissingen over energie-renovatie bewijst. Voor dit doel wordt de klassieke Expected Utility Theory (EUT) vergeleken met de Cumulative Prospect Theory (CPT), waarbij de laatste cognitieve vooroordelen bevat [183, 258, 451]. De belangrijkste gegevens voor deze analyses zijn afkomstig uit de energiemodules 2012 en 2018. De resultaten bevestigen de betere beschrijving van het feitelijke beslissingsgedrag van CPT in vergelijking met EUT. Bovendien zullen huishoudens die over het algemeen risico's en verlies vermijden, eerder investeren in energierenovaties dan anderen om de potentiële impact van verlies in de toekomst te voorkomen.

Het belang van transactiekostenbarrières voor energie-renovatie werd duidelijk in de eerste fase van dit proefschrift. In de derde fase van deze werkzaamheden wordt een meer gedetailleerd onderzoek uitgevoerd naar de transactiekostenbarrières voor energierenovaties en renovaties. De survey van het Housing Research Institute van de Technische Universiteit Delft vormde de basis voor deze analyses. Het is gebleken dat de tijd en moeite die nodig is om informatie te verkrijgen, de betrouwbaarheid van informatie en experts, en de complexiteit van het uitvoeren van de energie-renovatie worden geïdentificeerd als de belangrijkste transactiekostenbarrières voor huiseigenaren tijdens het energie-renovatieproces. Daarnaast vormen financiële vraagstukken, zoals dure energierenovaties, ondanks de enorme financiële steun van de Nederlandse overheid, nog steeds de grootste barrière voor energierenovaties. Deze specifieke belemmering kan derhalve verband houden met verborgen kosten, zoals de complexiteit van het aanvragen van leningen en subsidies, het feit dat huishoudens niet op de hoogte zijn van de beschikbaarheid van leningen en subsidies en de ongelijke verdeling van leningen en subsidies over huishoudens. Tot slot zijn de transactiekosten ook afhankelijk van het type renovatie. Het vinden van betrouwbare aannemers en de complexiteit van het uitvoeren van buitenrenovaties, evenals het beoordelen van uitgaven voor interieurrenovaties, zijn de belangrijkste transactiekostenbarrières voor verschillende renovaties.

De laatste fase valideert de bevindingen van dit proefschrift door middel van semi-gestructureerde interviews en focusgroepsessies met gemeentelijke projectmanagers en praktijkmensen die betrokken zijn bij de energietransitie. De resultaten van dit werk worden gebruikt om de potentiële mismatches tussen het huidige energiebeleid en de werkelijke behoeften van huiseigenaren te identificeren: (1) het gebrek aan energie-renovatie die zijn afgestemd op de behoeften van specifieke gebouw- en huishoudelijke groepen, (2) de noodzaak om de juiste boodschap en ambassadeur te gebruiken voor specifieke huishoudelijke groepen om energie-renovatie te bevorderen, (3) de ontoereikende implementatie van gedragsinterventies en nudges om energie-renovatie te bevorderen, en (4) het gebrek aan geïntegreerde financiële, informatieve en technische ondersteuning, met name voor huiseigenaren die geïnteresseerd zijn in energie-renovatie.

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Beleidsmakers kunnen de bevindingen van dit proefschrift gebruiken door gedragswetenschappelijke inzichten toe te passen om energie-renovatie te bevorderen en huiseigenaren te helpen transactiekostenbarrières te verminderen tijdens het retrofit-proces. Gedragswetenschappelijke inzichten kunnen worden gebruikt om oplossingen af te stemmen op de behoeften en kenmerken van huishoudens. Het gebruik van de juiste boodschap (comfortverbetering, onderhoud en kostenbesparingen) en de juiste ambassadeur (betrouwbaarheid, gedeelde identiteit en expertise) kan leiden tot hogere percentages energie-renovatie. De juiste boodschap kan ook inhouden dat aan risico- en verliesmijdende mensen de impact van energierenovaties wordt uitgelegd in termen van het verminderen van verlies/kosten. Het ontbreken van een geïntegreerd aanspreekpunt voor financiële, technische en informatieve hulp verlengt het proces, zelfs voor huiseigenaren die geïnteresseerd zijn in energie-renovatie. Het wegnemen van deze transactiekostenbarrières vereist de tussenkomst van een derde partij of een nieuw bureau dat de verschillende spelers in de markt met elkaar verbindt. Het concept van one-stop-stores is al in gebruik en moet op grotere schaal worden ontwikkeld dan slechts enkele steden in Nederland. Daarnaast kan een derde partij een digitaal platform zijn dat informatie geeft over verschillende aspecten zoals beschikbare leningen en subsidies en geschikte soorten energie-renovatie. Het platform kan ook aanbieders en klanten van energierenovaties bij elkaar brengen en beide marktpartijen veel tijd en moeite besparen.

1 Introduction

1.1 Background

1.1.1 Energy saving targets and the potential contribution of the owner-occupied housing

Retrofitted and sustainable buildings pave the way to achieving European energy saving targets, as buildings are responsible for more than one third of final energy consumption. However, only 1% of buildings are energy retrofitted each year and accelerating retrofitting is crucial to achieve the EU's 2050 climate neutrality target [126]. Owner-occupied homes account for more than half of the housing sector in the Netherlands and this sector consumes a large amount of natural gas, almost 71% of total energy consumption [129, 334]. Following the EU energy targets, the Netherlands has set the target of phasing out the use of natural gas in households and switching to renewable energy sources by 2050. Although switching to natural gas is generally considered essential for achieving the energy targets, the energy retrofit rate in the residential sector is still very low [312]

Energy labels and energy retrofit rates in the owner-occupied housing

The term renovation refers to any improvement in the performance of buildings, distinguishing between medium and large-scale changes. Energy retrofits are often associated with energy savings and usually result in an improvement in the energy rating of a dwelling from one energy label[1] to a higher level (e.g. from G to A). The importance of social aspects increases when energy refurbishments are carried out in residential buildings and have a direct impact on tenants/occupants [145, 336].

In the Netherlands, 34% of the housing stock, or 2.7 million homes, still have an energy label lower than C [385]. Fig 1.1 shows the distribution of owner-occupied housing with different energy labels in the Netherlands. In 2020, 93% of owner-occupied single-family homes still had a natural gas connection in their home. However, many households are trying to reduce their gas consumption through energy retrofits. For example, 86% of households have a HR boiler and 28% of households have solar panels in 2020 [384, 385]. The renovation rate refers to the percentage changes in the number of the identical houses moving from one energy label to the more efficient energy labels [106]. Sandberg et al. [389] simulated renovation rates in eleven European countries, including the Netherlands. They found that renovation rates are always stable and not high enough, ranging from 0.6 to 1.6 by 2050. Based on these renovation rates, it is unlikely that the EU's target renovation rates of 2.5-3% will be achieved in the residential sectors of these countries. Other studies carried out specifically for the Netherlands confirmed the very low renovation rates in the housing sector, including owner-occupied dwellings [106, 145]. Considering the low average energy label and the low renovation rates of the housing stock, the potential for adopting energy saving measures in owner-occupied housing is still very high.

1 The Energy Performance Certificate (EPC) indicates how much energy the buildinguses and measures the energy efficiency of the building. The most energy efficient buildings are marked with an EPC of A. The least energy efficient dwellings are given a G. The EPC is used to identify the most appropriate energy saving measures and to show how the energy performance of the dwelling can be improved, for example by insulating walls [101].

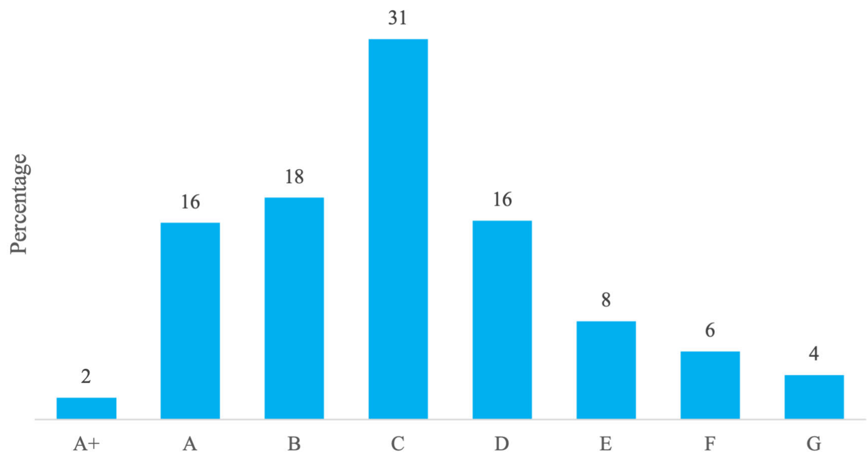

FIG. 1.1 Distribution of the owner-occupied housing with different energy labels in the 'The Netherlands energy module dataset of 2018'

1.1.2 Decision making and renovation processes of homeowners

The uptake of energy saving measures depends largely on households' knowledge of energy retrofits and their benefits [385]. Households may not even consider retrofitting their buildings because they are not aware of it, think it is unnecessary, or think that the buildings are in good condition. In addition, someone may know the benefits of an investment but not be motivated to do anything about it. Moreover, they may have other important expenses, such as the cost of repairing the elevator, or they may prefer to invest their money in the stock market [9, 384, 480].

The data show that households typically invest in energy retrofits for other reasons, such as to improve comfort, optimise building maintenance [35, 342, 384], if they have recently moved, or if they want to redesign the aesthetics of the home [310, 325, 326]. For example, when the roof is replaced. As part of this renovation, the household could also improve the insulation of the roof or install a solar system for the house. According to the experience of experts, people also like to install floor insulation because it significantly improves the thermal comfort of buildings. Cost savings on energy bills are another important motivation for some energy saving measures. For example, the installation of PV panels is quite cost-effective, while façade insulation is usually done when the house is purchased or maintained [109].

Homeowner characteristics are expected to be an important factor influencing energy retrofits. For example, younger households and households with higher incomes may be more willing to invest in energy retrofits than other groups [310, 325, 326]. In addition, social and personal norms, such as belonging to an environmentally friendly group in the neighbourhood, may increase the likelihood of being more willing to make energy-efficient renovations [156, 420]. Finally, when homeowners decide to undertake energy-efficient renovations, they may need to invest time in supervising the installation of energy-saving measures because the quality of the renovation depends on how trustworthy, reliable, and knowledgeable the expert or professional contractor is in performing the energy-efficient renovation. In addition, the household must expect that the installation will involve inconvenience and hassle [88, 109, 113, 376, 480].

Government programmes and public-private initiatives can help homeowners at different stages of the energy retrofit process. In the awareness phase, homeowners can learn about energy retrofits and their benefits, such as savings on utility bills or improved home comfort, through government, local agency letters, community energy events or social media. In addition, an aware person or a group of citizens can take action to increase awareness and organise the implementation of energy retrofits [61, 88].

After raising interest and awareness about energy retrofits, people may be motivated to undertake the energy retrofits, but may not continue the process due to various barriers. Experience shows that people may not proceed to the next steps because they do not know a reliable energy expert or do not have enough savings for energy retrofitting. External parties such as public authorities and public-private initiatives can help homeowners in this process with information, technical and financial support [113]. As far as financial support is concerned, the high investment costs for energy refurbishments currently necessitate the provision of grants/loans by the public authorities. However, financial support cannot be sustained in the long run, as the state cannot cover the costs of energy renovation for all households [176, 385].

1.1.3 Energy retrofits of owner-occupied housing in the Netherlands

Figure 1.2 shows the percentage of energy retrofits performed by homeowners in the five years prior to 2018 in the Netherlands. Among the energy retrofits, homeowners have frequently installed double glazing (20.2%) and sustainable heating (15.2%) [109]. In addition, 31% of homeowners have not invested in energy retrofits for a variety of reasons.

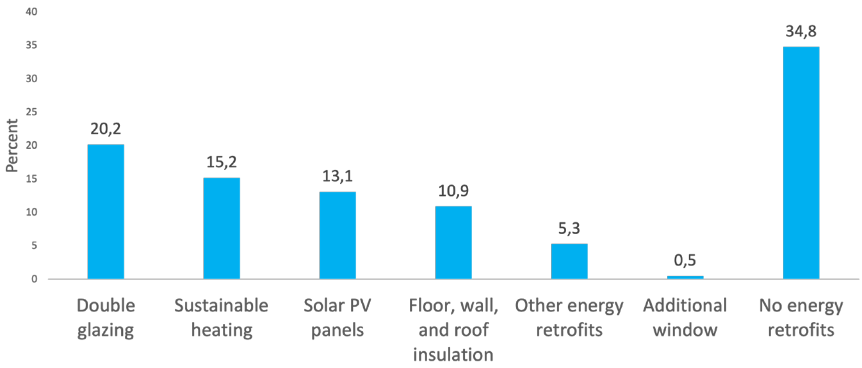

FIG. 1.2 The percentages of energy retrofits conducted by homeowners in the Netherlands using the dataset of 'The Netherlands energy module dataset of 2018'

The survey asked respondents for reasons why they do not make their buildings energy efficient. In the Netherlands, 41% of homeowners who have not made their building energy efficient in the last five years think that their building is already energy efficient. Therefore, they believe that no further energy retrofits are needed. The previous studies indicated that the households may not be well-aware of the energy performance of their buildings, as around 35% of these houses has energy label lower than C. In addition, 27% of homeowners expected a better energy labels than the actual ones. Homeowners may also believe that energy retrofitting is not necessary if the perceived difficulties are greater than the expected benefits [4, 91].

The second main category of obstacles cited by homeowners was financial. Homeowners cannot easily finance the energy retrofitting of their buildings and the procedures to apply for grants/loans are very complicated. In the Netherlands, mortgages from private banks[2] are the main financial support, so mortgages exceeding the house value are allowed to cover additional costs such as renovations and taxes. However, the complexity of these procedures might discourage homeowners from considering mortgages, and the expected benefits of energy renovation (in terms of money savings) are either not or only slightly higher than the cost of the mortgages [112]. According to another survey in the Netherlands, uncertainty about government policies, such as government financial support, is one of the main reasons why homeowners do not intend to make their buildings more energy efficient in the next five years [195].

2 The mortgage of the banking system depends on income and capital assets. Therefore, it is difficult for people with low incomes or young people in the early stages of their careers to obtain a loan.

There are many prominent events that can prompt homeowners to make their buildings more energy efficient (e.g., taking out a mortgage, moving, home maintenance). However, these occasions are often underutilised to provide information about sustainable housing. This is because service providers (e.g. financiers) and renovation and maintenance providers (e.g. builders) lack knowledge or interest in sustainable housing options. The lack of collaboration with local authorities, intermediaries and other parties involved in sustainable housing exacerbates this situation [374]. In the Netherlands, 12% of homeowners do not know how to make their buildings more energy efficient. Usually, homeowners have to hire a professional expert to do this. The expert can inform the homeowners about the costs and benefits in terms of cost savings and home comfort. Finding a reliable expert and information incurs additional costs and prolongs the energy retrofit process [480, 481]. In addition, homeowners may not invest in the most appropriate types of energy retrofits due to asymmetric and imperfect information [239, 316].

1.1.4 Examples of government programmes and public-private initiatives for owner-occupied housing in the Netherlands

The Dutch government has allocated special budgets to eliminate natural gas as an energy source by 2050. Between 2018 and 2028, 435 million euros were allocated for natural gas-free neighbourhoods. Subsidy schemes have been set up for various homeowners, including: (a) the Investment Grant for Sustainable Energy and Energy Savings (ISDE), which offers grants to homeowners and commercial users for the purchase of a solar boiler, a heat pump, connection to a heating network and insulation measures; (b) the Homeowner Energy Savings Grant (SEEH) for homeowner associations: for energy renovations or energy advice. The National Heat Fund also provides financing opportunities for more sustainable home and building design for homeowners and condominium associations. In addition, the energy tax has been adjusted to provide stronger incentives to phase out natural gas heating. The government has chosen the budget-neutral option, which increases the first-tier energy tax rate on natural gas by 4 cents per m^3 in 2020 and by 1 cent per m^3 in the following six years [375, 440].

In the Netherlands, the National Environment Centre (Milieu Centraal in Dutch) provides information on all the options for an energy efficient and sustainable home, subsidies and loans, energy experts and contractors, different approaches to saving energy with homeowner associations, a step-by-step plan for natural gas-free building. Despite the provision of information through various platforms, households still find it difficult to carry out the energy retrofits [300, 301].

In recent years, the role of local authorities has become more important in European countries. Local authorities can adapt national policies, for example by using locally available funding sources to accelerate energy retrofits in cities, and a neighbourhood-based approach to the built environment is being adopted (e.g. [179]). A study has shown that the effective design and implementation of policies and their preconditions vary widely across Dutch municipalities [468].

Local authorities facilitate the process of energy renovation by removing informational, financial and technical barriers. Dutch local authorities offer financial support to homeowners from national and local funds. Despite the huge financial support, homeowners still emphasise the lack of subsidies/loans as one of the main barriers. This barrier may be related to other barriers such as complexity of applying for loans/grants, lack of awareness among homeowners about the availability of financial support [112, 478].

Municipalities also provide information on various aspects of energy retrofits. The municipality of The Hague, for example, offers a free energy scan of buildings to homeowners interested in energy retrofits. As part of this programme, an external energy expert provides information on the appropriate types of energy retrofits for the buildings. While this removes one of the biggest obstacles, city experts explained that the results have not been as desirable as expected and many households have not made the energy retrofits because homeowners are still faced with the question of where and how to begin the energy retrofits [437]. Another example is the Regional Energy Desk, where homeowners can get information on available grants, reliable companies to perform energy retrofits, and customised solutions for living in an energy efficient and comfortable building. Local authorities, contractors and installers often work together so that homeowners can also get practical advice on technical measures and products [369].

One-stop shops or pop-up shops initiatives can operate independently or be part of government agencies. These shops, for example, raise awareness among households about energy retrofits. These types of shops also offer homeowners a whole package of financial, technical and informational support. The benefits of one-stop shops are the familiarity these shops have with the local market, the support they provide to building owners throughout the process, and the improvement in average energy efficiency through a holistic approach. Despite the great potential of one-stop shops, there are barriers to launching these shops, such as uncertainty about the customer base and the level of energy savings of the various energy retrofit packages [53].

1.2 Problem statement

As mentioned in the background section, average residential energy label and renovation rates are very low and not following the target renovation rates. Therefore, achieving energy targets in the housing sector is highly questionable. The government and local authorities are trying to target different groups of people to facilitate the decision-making and renovation process for energy retrofits. Authorities are also empirically assessing these factors as part of their programmes to design more effective residential energy policies. However, even they are uncertain which factors have the greatest influence.

The individual decision-making and renovation processes involved in energy retrofits are very complex. Homeowners go through different stages of the decision-making and renovation process: they consider energy renovations or not, they form their attitude towards energy renovations, they make final decisions, they carry out the renovation and finally they experience the energy renovations. During different stages, homeowners are influenced by various factors that motivate or discourage them from continuing the process. For example, homeowners face problems in finding: (a) financial support, (b) reliable information, e.g. on the appropriate type of energy retrofit, and (c) contractors. For example, due to lack of information/complex procedures, homeowners cannot simply borrow money from the bank to renovate their houses. Even when grants are available for energy retrofits, the information is often not easily accessible and transparent. As a result, homeowners find applying for grants cumbersome. In addition, there might be no guarantee of the quality of services, etc. [113, 394].

In the rental sector, social housing associations and national tenant unions promote and guarantee energy retrofits, for example, by establishing a voluntary agreement between responsible organisations to implement an energy programme [431]. In the owner-occupied sector, however, it is mainly the homeowners who are responsible for carrying out energy retrofits. For example, installing a heat pump requires more space than existing systems, such as a high efficiency gas boiler. In addition, finding and selecting reliable contractors to carry out the work and the likely disruption to the household are major obstacles. All of these factors complicate the decision and are often compounded by cognitive biases, i.e., systematic deviations from the norm or rationality in human judgement [88, 112, 202, 480].

1.3 Knowledge gap

Despite recent attention, our understanding of the impact of factors that influence behaviour during energy retrofit decision-making processes is limited. By oversimplifying user behaviour and neglecting behavioural factors in energy policy design, this could lead to inadequate results [93, 203]. Behaviour can be defined as "… activities in response to external or internal stimuli, including objectively observable activities, introspectively observable activities, and non-conscious processes." [457]. Individual behaviour is shaped as an interactive outcome of contextual, motivational, and personal factors [480].

A Contextual factors include household characteristics (e.g., size, composition, number of family members), sociodemographic variables (e.g., age, education, income, and employment), and property characteristics (e.g., construction year, type of dwelling, etc.). In addition, salient events such as a move and policy incentives such as subsidies are also included in this category of behavioural factors [480]. The impact of this category of behavioural factors on the renovation decision is limited in the literature.

B Motivational factors influence behavioural intentions and ultimately actual behaviour [12, 188, 189]. Household motivations need to be identified to drive residential energy retrofits [325, 342, 480]. Cost savings on energy bills, an increase in comfort and protecting environment are examples of motivating factors for energy retrofits. This thesis comprehensively examines the impact of motivating factors.

C Few studies have also examined the impact of personal factors on energy retrofit decisions. An example of personal factors is the way people evaluate information. People generally evaluate information based on their own perceptions to make decisions [163]. Therefore, people generally choose the energy-efficient measures that provide the greatest benefit compared to others [325, 326]. Factors such as awareness of energy use and perceptions of electricity/gas use in the home can influence energy efficiency choices in this way.

- Recent research has identified cognitive biases as an important barrier to residential energy efficiency retrofits, comparable to technical, financial, or institutional barriers [88, 478].. However, there is a lack of empirical research on the exact nature of these cognitive biases and the effectiveness of interventions to reduce biases. Understanding the cognitive biases that play a role in residential energy retrofit decisions and developing interventions to overcome them (i.e., bias reduction tools) can help increase the rate of residential energy retrofits. This work is one of the first attempts to assess the impact of cognitive biases on energy retrofit decisions.

Transaction costs (TCs) are the second category of barriers, along with psychological barriers such as cognitive biases and perceived difficulties. New institutional economists have developed transaction cost theory. TCs arise during the actual renovation through the transaction with external parties. Psychological barriers, on the other hand, occur mainly during the decision-making process. TCs and psychological barriers have differences and similarities which are explained later in this thesis [39, 313, 316, 480, 481].

Despite the importance of TC in achieving energy goals, few studies have examined household TC barriers [48, 190, 480]. Neglecting TC when assessing and preparing energy efficiency measures leads to sub-optimal decisions and resource allocations [453]. Transaction costs refer to non-monetary costs associated with different stages of the retrofit process for homeowners. These costs take various forms, such as time, effort, complexity in completing renovations, hassle, messiness, and uncertainty. For example, renovators need to compare different types of energy retrofit measures to find the most appropriate one(s) in terms of cost and quality. This can lengthen the duration of the renovation process and add significant overhead [81, 453].

As a main contribution to the current literature, this thesis examines the importance of the main influencing factors using the behavioural and transaction cost perspective. The thesis develops an integrated framework of both categories of factors in order to have a more holistic view of the process of energy retrofits.

1.4 Aims and Research Questions

Aims

This thesis aims to understand the decision-making and renovation processes of homeowners by using the behavioural and transaction cost perspectives. The objectives are therefore (1) to evaluate the main factors influencing behaviour including cognitive biases during the decision-making process of homeowners in energy renovation, and (2) to investigate the transaction cost barriers during the renovation process. In addition, policy instruments to promote energy retrofits and to reduce barriers are evaluated using the main identified factors influencing behaviour and the main identified transaction cost barriers.

Research Questions (RQs)

The main research question of the thesis is:

How to improve the individual decision making and the process of energy retrofitting using the behavioural and transaction cost perspectives?

Five key questions are defined to answer the main research question (Fig 1.3):

1. **How can the behavioural factors and transaction cost barriers influence the decision-making and renovation processes of homeowners towards energy retrofits?**

2. **What are the most important factors influencing the behaviour of homeowners during the decision-making process for energy retrofits?**
   - Which contextual, motivational, and personal factors significantly determine the homeowners’ behaviours towards energy retrofits?
   - Which cognitive biases significantly determine the homeowners’ behaviours towards energy retrofits?

3. **What are the main transaction cost barriers during the renovation process for the homeowners in the Netherlands?**

4. **How can the outcomes of this thesis be used to evaluate the potential misalignment of the current policies in promoting energy efficiency renovations in the Dutch owner-occupied sector?**

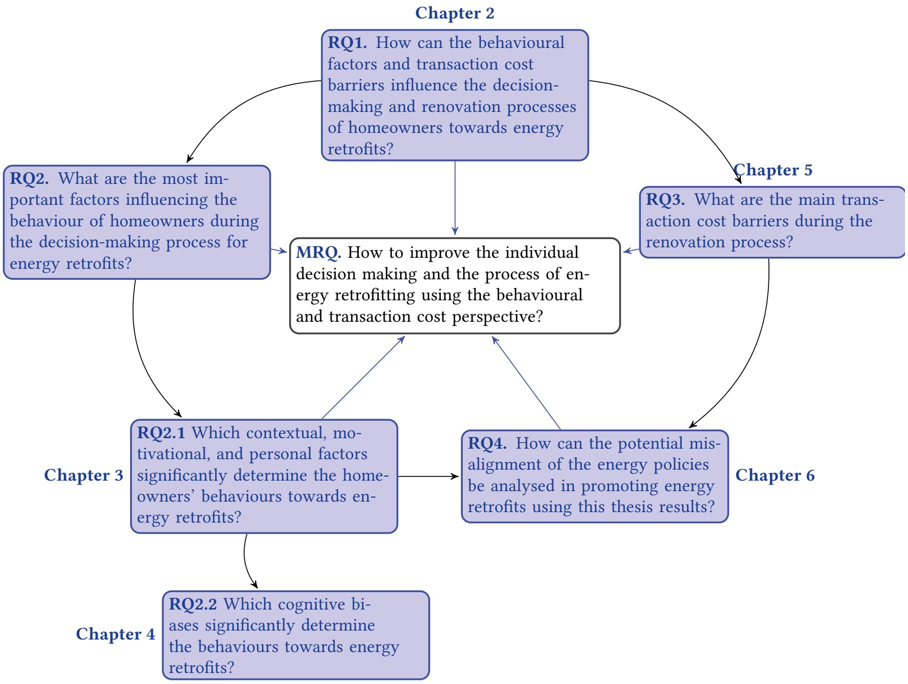

FIG. 1.3 Thesis connections of research questions and the associated chapters

1.4.1 Research scope

As mentioned earlier, reducing energy demand in the residential sector can contribute significantly to achieving energy goals. Energy retrofits occur in the nonprofit, private rental, and owner-occupied housing sectors. In the non-profit housing sector, energy retrofits are managed by a central organisation, such as a housing association, which is responsible for decision-making and implementation of energy retrofits. The non-profit housing sector has access to more resources, either information or financial support. In private rented housing, the landlord is primarily responsible for implementing energy retrofits, but tenants also benefit from better energy efficiency in their homes. Therefore, the interaction between tenant and landlord must also be taken into account. The share of private rented housing is lower compared to the other two sectors, 13%. Decision making in the owner-occupied sector is decentralised and each individual makes decisions based on their conditions and the different characteristics of households and buildings.

Moreover, the owner-occupied sector has the highest share of the housing sector in the Netherlands, almost 60%. Therefore, this thesis focuses on the owner-occupied sector in the Netherlands.

Many actors are involved in the implementation of energy efficiency renovations, including policy makers, suppliers, contractors, and homeowner associations. This work focuses mainly on individual homeowners and other actors' behaviours have not been investigated. In the Netherlands, for example, a large percentage of homeowners live in multi-family dwellings and decisions about energy retrofitting of this category of dwellings are mainly made by homeowner associations.

Furthermore, this work aims to evaluate current policies based on the results of the study on homeowner behaviour and transaction cost barriers. However, the recommendations for policy makers are not tested in this work. Moreover, behavioural policies and incentives have proven to be one of the cost-effective policy tools in recent years. This work examines these types of incentives, but has not designed and tested behavioural interventions or nudges.

Renovation decisions and the actual renovation process consist of different phases, which can be divided into pre-renovation (decision making process), renovation and post-renovation (experiencing and selling the house). This work mainly examines the influencing factors during the decision-making and renovation process of individual homeowners. The main factors influencing behaviour were assessed for each stage of decision making and the transaction cost barriers during the renovation process were investigated. The study of homeowner behaviour after renovation is very important but beyond the scope of this work.

The behavioural factors are drawn from the behavioural economics and social psychology literature with applications to the energy sector, as well as from research on housing quality. The institutional economics literature, also with applications to the energy sector, is examined to assess transaction cost barriers. Mathematical modelling is used to examine cognitive biases. However, social psychologists and behavioural economists also use experiments to test the cognitive biases and their effects on investment decisions. In this work, regression analysis and mathematical modelling are mainly used to evaluate the effects of behavioural biases and transaction cost barriers.

This work focuses mainly on energy retrofits such as double glazing, insulation of walls, roof and floors, photovoltaic panels and sustainable heating systems. Energy retrofits are usually carried out together with other types of renovations. Therefore, this work also explores the barriers to carrying out renovations. By facilitating the

TOC

renovation process, energy retrofits can also be encouraged. In addition, the five studies in this thesis examine individual decision-making processes and renovation procedures. Specific categories of behavioural and transaction cost factors are examined, which together explain the behaviour of homeowners towards different types of renovations and energy renovations.

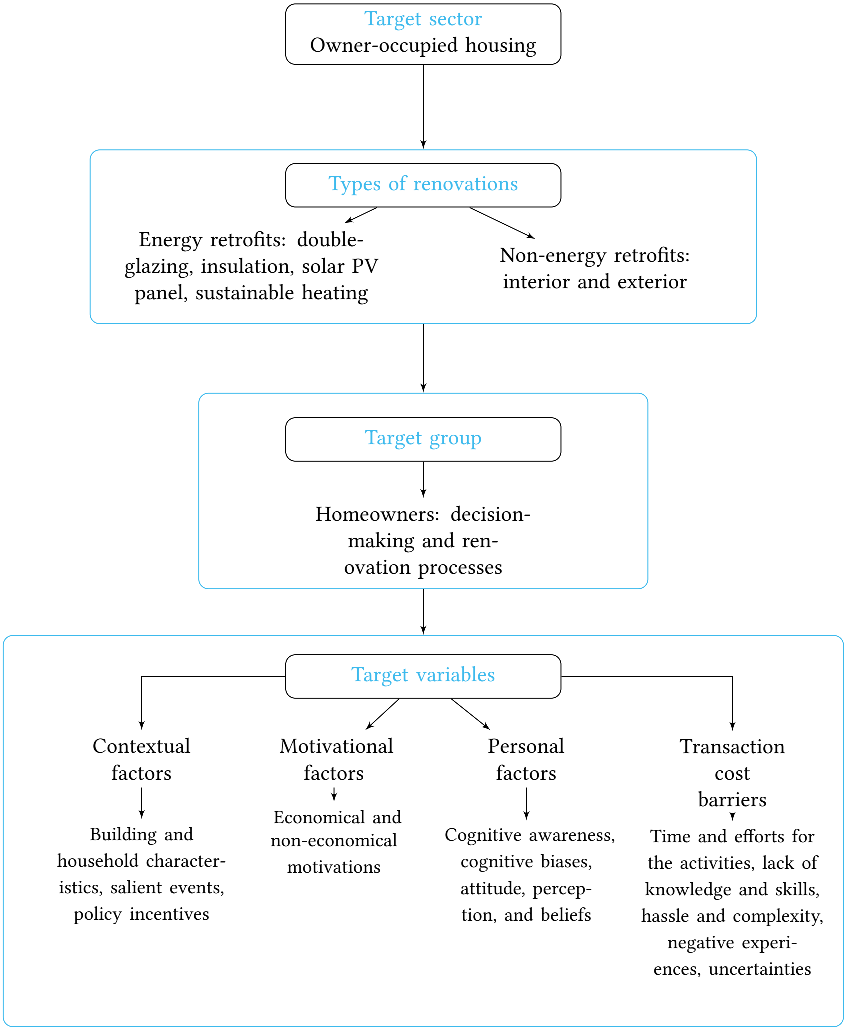

FIG. 1.4 Scope of the thesis

1.5 Structure of the thesis

This thesis comprises five main studies that together address the main objective and research questions defined in the previous subsection 1.4. *Chapter 1* provides an overview of this thesis, including the main problem, research questions, social and scientific relevance, and structure of this thesis. *Chapter 2* develops an integrated framework of behavioural factors and transaction cost barriers. It also examines the general importance of behavioural factors and transaction cost barriers to energy retrofits. The results of this chapter demonstrate the importance of both categories of influencing factors. In *Chapters 3, 4 and 5*, the lists of behavioural factors and transaction cost factors are extended in more detail to different types of energy refurbishments (double glazing, insulation, solar panels and sustainable heating system) and refurbishments (external and internal). *Chapter 6* validates the findings of previous studies with evidence from policy makers. In addition, households may need to make decisions collectively, e.g. people living in multi-family dwellings. The conclusion, discussions and recommendations for the future research are presented in Chapter 7. A more detailed explanation of each study is provided in the following paragraphs.

In line with the main objectives of this thesis, *Chapter 2* assesses the importance of behavioural factors and transaction cost barriers to energy efficiency retrofits. The purpose of this chapter is to test the hypothesis of whether behavioural factors and transaction cost barriers are important influencing factors for energy retrofits. This chapter describes recent policy incentives and public-private partnerships to promote energy retrofits in owner-occupied housing. A theoretical framework is developed that includes the different stages of the energy retrofit process and the main influencing factors. The results confirm the importance of these influencing factors.

Psychological factors belong to the category of behavioural factors. Empirical research on the importance of psychological factors is scarce in the existing literature. As a contribution to the main objective of this thesis, *Chapter 3* mainly examines the impact of psychological factors together with the other main factors of contextual, motivational, personal influences on energy renovations. Contextual factors include building and household characteristics, as well as salient events such as a move. Examples of motivating factors include improving thermal comfort and improving the maintenance condition of the home. Personal factors explored in this study include awareness of energy use, household perceptions of energy use relative to other households, conscious replacement of non-energy efficient appliances with energy efficient appliances, and conscious reduction of gas and electricity use. The result of this study also confirm the importance of personal factors.

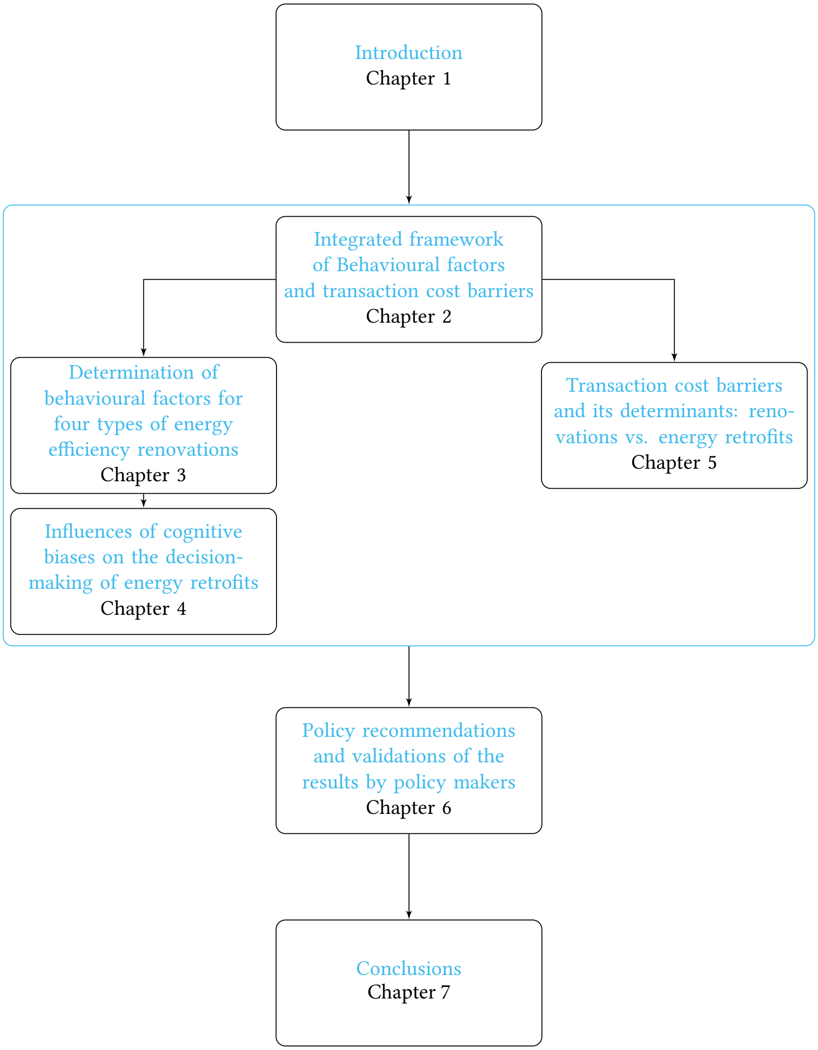

FIG. 1.5 Structure of the thesis

Following *Chapter 3*, *Chapter 4* expands the list of behavioural factors and examines the effects of cognitive biases on energy retrofit decisions. This chapter is mainly concerned with the empirical investigation of cognitive biases during the decision-making process of energy retrofits. It is hypothesised that mathematical models can more accurately predict energy retrofit decisions when cognitive biases are taken into account. The results show that CPT can more accurately predict decisions about energy retrofits. Cognitive bias parameters are estimated for four clusters and for two types of energy saving measures - double glazing and insulation. The clusters of houses are derived using building and household characteristics.

Chapter 5 mainly focuses on transaction costs, explaining the determining factors and categorising them into transactor and transaction characteristics and institutional aspects. The transaction cost barriers are identified for each stage of renovation. Then, the importance of TC factors is assessed for renovation and energy renovation and for two groups of households, i.e. renovators and potential renovators. It is assumed that transaction cost barriers differ for renovation and energy renovation. The results suggest different transaction cost barriers for renovation and energy renovation.

Chapter 6 validates the results of previous chapters using the insights of policy makers and practitioners. Key motivations and transaction cost barriers are explored through semi-structured interviews and focus groups with policy makers and practitioner experts. This chapter tests several hypotheses, such as the establishment of a new agency to implement energy efficiency retrofits and the question of the right message and ambassador to promote sustainability. *Chapter 7* provides the conclusions and recommendations of the thesis.

TABLE 1.1 The research methods and the structure of this thesis

	Research flow	Research methods	Research results
Chapter 1	- Introduction		
Chapter 2	- Developing an integrated framework of behavioural factors and transaction cost barriers - Investigation of the significant impacts of these factors	- Expert interviews logistic regressions	- Evaluation of the impacts of behavioural factors and transaction cost barriers for energy retrofits
Chapter 3	- Identification of contextual, motivational and personal factors	- Expert interviews - Logistic regressions	- Investigation of behaviour influencing factors on four types of energy efficiency renovations
Chapter 4	- Investigation of cognitive biases during the decision-making process	- Cluster analyses genetic algorithm cumulative prospect theory	- Identification of cognitive biases for two types of energy efficiency renovations
Chapter 5	- Identification of transaction cost barriers: renovation and energy efficiency renovation	- Expert interviews - logistic regressions	- Comparison of the transaction cost barriers for renovation and energy efficiency renovations
Chapter 6	- Validation of the integrated framework of behaviour-related factors and transaction cost barriers by policy makers and practitioners: individual decision-making processes	- Expert interviews - Focus group - Theory	- Recommendations for policy interventions - Investigations of the type and conditions of a potential new agency in promoting sustainable renovation
Chapter 7	- Conclusions and Recommendation		

1.5.1 Research methodology

The research methodology comes from behavioural science and transaction cost barrier research to understand the decision-making process of homeowners regarding energy retrofits. In addition, evaluation of current energy policies is one of the main components of this research. For this purpose, the current status of these policies is compared with the actual needs of homeowners.

The Dutch owner-occupied housing sector is the case study of this thesis. Empirical studies are mainly conducted to validate the theoretical framework and to conduct ex-ante and ex-post studies. From the ex-post perspective, the impact of behavioural factors and transaction cost barriers on investment decisions and the actual implementation of energy retrofit measures are investigated. From the ex-ante perspective, the potential impact of these influencing factors on potential investment decisions and implementation of energy efficiency measures by individuals are examined. Five specific studies will be conducted, including: (a) the development and validation of an integrated framework of behavioural factors and transaction cost barriers to energy retrofits, (b) the identification and analysis of the impact of behavioural factors, including contextual, personal, and motivational factors, on energy retrofits, (c) the identification and analysis of the impact of cognitive biases on energy efficiency investments, (d) the identification and analysis of transaction cost barriers to renovations and energy retrofits, (e) the validation of key findings by policy makers and practitioners. The different methods of analyses and the specific datasets are explained below.

Research methods and datasets

To achieve the objective of this study, various research methods will be used including desktop research, statistical analysis, regression and cluster analysis, optimisation algorithms, expert interviews and focus group sessions to validate the findings. In addition, a comprehensive list of policy incentives and public-private initiatives are examined to assess the effectiveness of these instruments in addressing identified key behavioural factors and transaction cost barriers. The datasets for each study are presented in the following paragraphs.

Chapter 2 examines the effects of the influencing factors, i.e. behavioural factors and transaction cost barriers on energy efficiency retrofits. First, an integrated framework of behavioural factors and transaction cost barriers is developed based on the literature review. Then, the expected effects of these factors are examined using regression analysis. The dependent variable is whether households have implemented or intend to implement certain energy saving measures in the past or in the future. The independent variables are the factors that influence behaviour and the transaction cost barriers. Every 5 to 6 years, the Dutch Ministry of the Interior and Kingdom Relations conducts a survey on energy consumption, household energy behaviour and household investment behaviour in relation to energy saving measures in the rental and private building stock. This survey is conducted as part of a larger survey of the Dutch housing stock (WoON - Woon Onderzoek Nederland, which translates as Netherlands Housing Survey). All researchers can access this dataset. In this chapter, the 2012 energy module was used, which includes both behavioural and transaction cost factors.

To examine behavioural factors in more detail, Chapter 3 will assess the influence of a specific group of personal factors, including psychological factors, on energy retrofitting. A theoretical framework that includes contextual (e.g. building characteristics), personal (e.g. awareness of energy consumption) and motivational factors (e.g. improving thermal home comfort) for the decision-making processes. The effects of these factors are examined using logistic regression analysis for four types of energy saving measures: double glazing, insulation, solar panel, and sustainable heating system. The analyses are performed for renovators and potential renovators. The 2018 energy module is used for this part. This data set includes, in particular, “the psychological factors, but also other factors that steer behaviour.”

As mentioned earlier, there are few empirical studies in the literature on the effects of psychological factors and, in particular, cognitive biases. Chapter 4 expands on behavioural factors and examines the effects of cognitive biases on energy retrofit decisions. Expected utility theory (rational decision makers) and cumulative prospect theory (decision makers facing risks, uncertainties and cognitive biases) are also applied to examine the impact of cognitive biases on individuals’ decision-making processes for energy retrofits. Expected utility theory and cumulative prospect theory parameters are estimated for four groups of individuals and two types of energy retrofits - double glazing and insulation. Cluster analyses are performed using grey relational analysis and the K-means clustering method. Due to the nonlinear parameters, the genetic algorithm is used to measure the parameters of expected utility theory and cumulative prospect theory. For this study, the 2012 and 2018 energy modules are used to validate and compare the results of the parameters of the expected utility theory and the cumulative prospect theory.

After examining the impact of behavioural factors, it is necessary to examine the importance of transaction cost barriers, as these barriers prolong the process of energy efficiency retrofitting or make it unpleasant. The hypothesis is that transaction cost barriers are different for renovations and energy efficiency retrofits. Chapter 5 examines transaction cost barriers and their determinants to provide a more comprehensive overview of these factors and a comparison of their impact on energy efficiency retrofits and renovations. First, a theoretical framework is developed to consider the transaction costs for the different phases. A logistic regression analysis is performed for this study. For this part, the OTB household survey is used, which contains information on the transaction cost barriers of renovations and energy retrofits for two groups of homeowners: renovators and potential renovators. The survey was conducted in 2012 among 3,776 homeowners in the Netherlands.

Chapter 6 focuses on validating the findings from the previous chapters. This final study adopts a qualitative approach and validates the findings of the previous study through semi-structured interviews and focus group sessions with experts and practitioners. Policy makers and practitioners confirm the practical feasibility of the behavioural measures and incentives recommended in the previous studies.

1.6 Added values of the research

In this section, the scientific and societal contributions of the research are demonstrated.

1.6.1 Scientific contribution

This research has addressed the internal struggles during the investment decision-making process and the external interactions of homeowners in the implementation of energy efficiency retrofits. The main scholarly contribution of this work is the development and application of an integrated theoretical framework that encompasses the internal and external processes of energy efficiency retrofits and the factors that influence these two processes among individual homeowners. This framework provides a holistic view of retrofit decisions and the actual retrofit process. In addition, the challenges and opportunities faced by individual homeowners were explored through a case study in the Netherlands. Behavioural research is used to investigate the factors influencing the decision-making processes. Transaction cost barriers are investigated to explore the barriers created by the interaction with external parties such as policy makers, suppliers and contractors.

The findings from different disciplines are combined to clarify these influencing factors. Insights from new institutional economics (specific to TC), behavioural economics, and social psychology on energy efficiency are used to identify the factors that influence behaviour as well as transaction cost barriers. Empirical studies examining the effects of psychological factors are very scarce in the literature. Psychological factors, particularly cognitive biases, are examined using the behavioural economics and social psychology literature on energy efficiency. Classical economics assumes that people make rational decisions. Behavioural economics takes into account people's irrational behaviours and is probably better able to predict actual behaviour. Originally, they relied on evidence-based experiments. More recently, however, they have also employed the full range of methods used by economists. This group of scholars is defined not by research methods but by the application of psychological insights to economics [73]. Social psychology points out that individuals act in a broad social context, such as taking social motives into account when making decisions, and that their behaviour has larger and more lasting effects [354]. They use three types of methods, including observational methods, correlational methods, and experimental methods, to provide empirical answers to questions about social behaviour [142, 280]. In the Netherlands, the national household survey is unique compared to other countries. These datasets allow the assessment of these groups of factors.

1.6.2 Expected policy contribution

Policy makers can use the results of this study to design or modify policy instruments to promote energy efficiency renovations in owner-occupied buildings. The effectiveness of current policy incentives can be improved if these behavioural factors and transaction cost barriers are considered when designing policy incentives. The traditional energy policies, e.g. provision of subsidies and increasing taxation on non-renewable energy sources, can be more effective if these policies are integrated with behaviorial interventions and nudges. This dissertation aims to recommend few behaviorial interventions and nudges based on the identified behaviorial factors and more specifically the cognitive biases. For example, the most important motivational factors are improving comfort, saving money, and the maintenance state of the buildings. When these motivational factors are taken into account, policy makers can incentivise energy retrofits by translating them into comfort improvements and money savings. In addition, policy makers aim to reduce the monetary and non-monetary barriers for energy efficiency renovations. The potential approaches for eliminating or reducing the barriers can be identified based on the main identified barriers during the implementation of energy retrofits of this dissertation.

1.6.3 Societal contribution

In this thesis, the main obstacles and influencing factors on homeowners' behaviour during the decision-making and renovation process are investigated. The results of this research can facilitate renovation decisions and the actual renovation process for individual homeowners. By knowing or mapping the biases and obstacles, individual homeowners can "plan" their journey to a greener home. They can try to identify these barriers and remove them one by one. This thesis also explores several categories of barriers and influencing factors, such as the lack of reliable information and experts, and cognitive biases. Homeowners can identify key barriers (monetary and non-monetary) and potential solutions to reduce/eliminate key barriers.

Providers of services and energy efficient technologies can also benefit from the results of this dissertation, as the goal is to clarify the potential contribution of these actors to facilitate energy retrofits.

2 Unravelling the Dutch homeowner behaviours

Published as: Ebrahimigharehbaghi, S., Qian, Q.K., Meijer, F.M. and Visscher, H.J., 2019. Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making?. Energy Policy, 129, pp.546-561. PhD candidate conducted the conceptualisation, methodology, formal analysis, writing, data curation, revision.

Note: This dissertation aims to investigate the main influencing factors on the energy efficiency renovation decision. The behavioural factors and transaction cost barriers have not been addressed comprehensively in previous research. This chapter explains the drivers and barriers of energy efficiency renovations among the homeowners living in the Netherlands. The Netherlands energy module 2012 is used which contains the information of 2,784 homeowners in the Netherlands. This dataset includes the household and building characteristics, the non-monetary costs of conducting energy efficiency renovation. This chapter explains the current public/private partnerships for promoting energy efficiency renovations. Afterwards, the main behavioural factors and transaction cost barriers are identified. Furthermore, the potential improvements for policy implications are discussed using the results of the drivers and barriers to adopt the energy efficiency renovations.

ABSTRACT

The housing stock has a considerable share of 40% in energy consumption and 36% of CO_2 emissions in the EU. In accordance to energy efficiency and emissions targets set by EU, The Netherlands has aimed to renovate 300,000 homes each year, leading to 50% reduction in CO_2 emissions, by 2050. Many factors including low renovation rates create uncertainties in achieving these targets. The current study aims for understanding the barriers and drivers towards energy efficiency renovations (EERs) amongst Dutch homeowners, and to aid in gaining a better insight into the role of public authorities in promoting EERs. First, the extrinsic drivers, including policies and other initiatives in the EER process are explained. Second, the intrinsic drivers and intrinsic/extrinsic barriers are explored. Regression analyses are performed on the national Dutch survey data for renovators and potential renovators. Our main findings include: (a) desire to enhance the quality of their life, rather than the financial benefits, etc. is identified as the main driver; (b) the main barriers are the

costs of EERs, complexities in the process, information barriers, and finding reliable experts and information; (c) For improvement in meeting renovation targets, the current Dutch policies need to consider all the decision criteria by homeowners, such as: Reducing the complexities; Time needed to obtain loans and subsidies; and Facilitating access to information.

KEYWORDS Energy Efficiency Renovation; Homeowner; Housing; Barriers; Drivers; Behavioural Factors; Transaction Costs (TCs); Policy instruments; Decision-making

2.1 Introduction

Many countries have realised the need to save energy and transition to renewable energies. Member states of the European Union (EU) aim to complete the change towards renewable energy sources by 2050. This energy transition includes: shifting away from fossil fuels; electrifying the heating demand, increasing the awareness of residents; and amending energy taxes in favour of renewable energies. In the Netherlands, the Ministry of Economic Affairs has issued a new policy to encourage actions that would help people eliminate the use of natural gas in the heating sector by 2050, and, by then, to completely use renewable energy [174, 458]. Yet, despite defining these targets, in recent years, the renovation rates have not been fast enough in achieving the policy targets [32, 74, 145].

Energy efficiency programmes at both national and international levels contribute to reaching the energy saving targets. These programmes aim to remove the barriers and facilitate the process of Energy Efficiency Renovations (EERs) [320]. In the EU, the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) are the main legislative instruments that guide the adoption of energy efficiency renovations. For both new and old buildings, they promote these measures by the building approval procedures and the energy performance certificates/labels, respectively [465]. At the national level, the Dutch government defines national policies that shall be achieved by local authorities. For instance, Dutch housing associations and municipalities contribute to the achievement of energy targets. Together with its members, the Dutch association of social housing organisations (Aedes) undertakes action on the non-profit housing stock. In the rental sector, social housing associations and national tenant unions facilitate and ensure EERs, for instance, by making a voluntary agreement among the responsible organisations to operate an energy programme [431]. However, in the owner-occupied sector, homeowners are entirely responsible themselves for carrying out EERs. In the case of in multi-family properties such as apartments, homeowners are required to organise themselves in an association of apartment owners, but even then, it appears difficult to reach an agreement about joint investments in energy saving [145].

In 2017, the Dutch owner-occupied sector accounted for 69.4% of the building stock, and currently, the overall average energy label performance is at the mid-point 'D' on a scale from A to G [172, 174, 307]. Considering the significant share of the housing stock in total annual energy consumption, and relatively low average energy label, there is a considerable energy-saving potential in the owner-occupied sector. Moreover, the processes of EERs are not easy, and homeowners encounter issues in finding: (a) financial support; (b) reliable information; and (c) contractors [480]. For instance, homeowners cannot easily raise money to renovate their buildings, and the procedures associated with EERs are very complicated. In the Netherlands, mortgages by private banks[3] are the most important financial support, and so mortgages more than the house value are allowed to cover additional costs, such as renovations and taxes. However, the complexities of these procedures might prevent homeowners from considering mortgages, and the expected benefits of EERs (in terms of saving money) are either not higher or only marginally higher than the costs of mortgages [394].

From economic perspective, the behavioural aspects and transaction cost (TC) factors are among the main influencing factors in the consumers' decision-making processes. Behavioural factors mainly illustrate a range of personal, contextual and external factors influencing homeowners' cognitive decision-making processes. The personal factors include cognitive awareness, attitudes and beliefs, experience and skills, while the contextual factors contain homeowners' features, socio-demographics and property characteristics. Also, behaviour can be influenced by external factors, such as other people's behaviours. The transaction cost (TC) means any hidden cost that has not been included in the cost analysis and that has been generated owing to a transaction with an external source. Asset specificity, uncertainty in the decision-making processes, and frequencies are the determinants of TC. Examples are time and effort to acquire knowledge, information and finding reliable experts [35, 313, 316, 478, 480].

3 The mortgage of the banking system depends on income and capital assets. Therefore, it is difficult for people with low incomes or young people in the early stages of their careers to obtain a loan.

The aim of this paper is to evaluate the influencing factors in EERs among Dutch homeowners. We intend to fill the literature gap by addressing the drivers and barriers to EERs from the behavioural research and TCs perspectives, and evaluating recent Dutch policy instruments. The behavioural research studies are mainly reviewed to investigate the drivers of EERs. The TC studies are used to identify the non-monetary cost barriers. The main question is 'Which factors influence the decision-making processes of Dutch homeowners towards EERs?' Through this study, the current policy instruments are examined to indicate whether these policies match the needs of homeowners. Hence, the results of this study aim to facilitate EER processes for homeowners, and to help in designing more effective policy instruments. The WOON2012 energy module database (housing survey on energy uses in rental and private building stocks in the Netherlands) is used to quantitatively analyse the impacts of the factors influencing the decisions of Dutch homeowners.

The remainder of the paper is structured as follows. Section 2 reviews scholarly investigations under two headings: (1) the recent policies/ initiatives to promote EERs in the European countries and the Dutch owner-occupied sector; and (2) drivers and barriers towards EERs in the owner-occupied sector. Section 3 describes the methodology, explains the WOON2012 energy module database, and then continues the analysis by logistic regression. Sections 4, 5, and 6 present subsequently the results of the analyses (Section 4), discussion on these results (Section 5), and conclusions and policy implications (Section 6).

2.2 Review of Earlier Studies

2.2.1 European policies in the owner-occupied sector

For owner-occupiers, the lack of awareness, the absence of sufficient knowledge and the lack of cost effectiveness and funding are often seen as the main barriers to undertake energy efficiency measures. However every homeowner is confronted with its own individual and personal barriers that largely are related to their household, dwelling characteristics and their personal beliefs and convictions. Schleich et al [396] studied the adoption of energy efficiency technologies by income categories in eight European Union countries, and recommended that the financial supports should address "poor homeowners".

Over the last decades the Member States of European Union have undertaken serious efforts to promote energy efficiency in the housing sector. Ambitious energy saving goals were set and national, regional and local authorities have designed a mix of policy instruments to conquer the barriers homeowners are confronted with. Although the definition of policy instruments is not completely unanimous in the research literature, a distinction is usually made between regulatory, economic, organisational and communicative instruments (e.g. [211, 213, 241]). The precise contents and goals of these national policy instruments vary, but the common goal is to motivate and stimulate owners to undertake action by tackling the barriers that prevent them from renovating their dwellings in an energy efficient way.

Over recent years the importance of the role of local authorities has increased in European countries (e.g. [179]). It is in this respect predominantly acknowledged that, instead of a common national policy approach, an approach is needed that is based in local authorities and its neighbourhoods. In order to change the individual behaviour and perspectives of owners, policies throughout Europe are increasingly based on identifying the individual needs, possibilities and wishes of homeowners and connecting their demands with the supply side. In this way, policy instruments can play an important role in helping to eliminate the above mentioned barriers (e.g. [40, 138, 238, 240, 283]).

Only a few studies have comprehensively examined the Dutch policy instruments [319,321, 431, 464, 465, 46]. Tambach, Hasselaar, and Itard [431] analysed the policies for the housing sector. The significant part of their research is assigned to the interviews with local actors regarding the barriers and needs for energy transitions, including the means to influence attitudes of agents towards energy-saving. They concluded the Dutch system needs a stable and long-term financial support to build trusts in the owner-occupied sector. Vringer et al [469] mentioned that the Dutch policy instruments are not too strong, and homeowners need more governmental interventions. They proposed that if the current taxes depend on homeowners' energy label, the homeowners will be more motivated in doing EERs. Murphy et al [319] explored and evaluated the underlying theories of policy instruments. They found the objectives often change during the implementation, with the result that achievement of those objectives remains uncertain. The majority of policies emerge and fade over short-time periods. Moreover, the current policies are not effectively combined to achieve the targets of energy efficiency. The authors recommended to examine the precise impact of policies and to consider elements beyond the effectiveness of policies, such as equity.

The Energy Efficiency Directive (EED) aims to reduce the energy consumption by 20% in 2020. Article 4 of the EED obligates European Member States to build a long-term strategy for the renovation of the buildings. The Dutch Energy Agreement signed in 2013 by 40 parties (public and private) is the response to the mandatory objectives of the EED. At the end of 2016, the Energy Agenda was presented by the Dutch Cabinet. The agenda outlines the extensive long-term lines by 2050 [115].

In the Energy Agreement and Energy Agenda, several actions are planned and implemented to promote energy-saving in the owner-occupied sector. A new public funding has been available since 2014 for the building sector and part of this funding is devoted explicitly to the homeowners and housing cooperatives under the name of 'National Energy Fund'[216].

In the building sector in the Netherlands, the energy transition policies are designed to entirely move to the use of renewable energy resources. These policies include: 1) Nearly zero energy indicators for new buildings by 2020; 2) Large scale energy renovations for lower EPC (Energy Performance Certificate)-Levels (D and F); 3) Subsidies for heat from renewable sources, more use of solar PV; 4) Raising the awareness of households about renewable energy resources, and 5) Switching to electricity for energy use [458].

TABLE 2.1 The main Dutch (policy) instruments for homeowners' EERs

Policies at the national level	Underlying hypothesis	Date active
More national revolving fund for energy-saving, (€ 50 million), reducing the interest rates	Providing financial support	Issued in 2016
Cheaper mortgages in return for energy efficiency (depending on the bank)		the mortgages are lowered in the 1st half of 2016
'Save Energy Now!' - Applying for a grant/low-interest loan - Encouraging homeowners by a campaign with an energy label C/ lower	Reducing financial & information barriers	2017-2020
'Energy-saving at home subsidy scheme' - A budget of € 60 million for homeowners - At least two major insulation measures - For an integral and extremely low-energy package (the insulation package with a zero-energy home): A bonus of € 4000 over and above the subsidy is available A subsidy is also available for energy recommendations and for creating a green long-term maintenance programme for owners' associations	Providing financial support	1st September 2016
Providing a 'sustainable providers' profile, who supply homeowners more suitable products/services for energy-saving measures	Removing the barriers in finding reliable experts	The profile was available at the end of 2016
Steering group: they ensure the cooperation between responsible organisations for energy saving in the regions	Reducing the complexities in the working process	2017-2020
Legal anchoring of object-related financing in Coalition Agreement Adaptation of the Wet Vet (= Bill on the progress of energy transition) that enables the role of network companies in the sustainability of housing	Aim to remove the current obstacles	Part of it in the 1st July 2018 The rest will be on 1st January 2019
Further elaboration of the care and financing model for the private homeowners Building on experiences in the regulated rental sector, further developing a tender system for upscaling, innovation and price reduction	Providing financial supports	2018 and beyond

TABLE 2.2 The main Dutch private/public-private initiatives for homeowner EERs

Private/public-private parties initiatives	Underlying hypothesis	Date active
'Get out of your chair' (both homeowners and companies): An initiative from energy providers - Promoting energy saving by the advertisements - Informing the benefits, available services and products, and financial supports to EERs by the municipalities - For a two-week period, commercials were circulated on television and radio - Energy companies post their energy saving products on a campaign website	Informing the benefits of using the energy - saving measures	Two weeks in 2016
Innovative Approaches Owner-occupied Homes By VNG coordinates the programme in collaboration with the Dutch entrepreneurial organisation for construction and infrastructure - Municipalities, together with local entrepreneurs and energy cooperatives - Renovate private owner-occupied homes in 51 Innovative Approaches innovative - The scheme focuses on alliances with innovative ideas to encourage homeowners to renovate their homes to energy-neutral - An independent assessment committee checks the applications and the progress of the approaches - Municipalities, together with local entrepreneurs and energy cooperatives, contribute of up to € 200,000 - To speed up the transition to an energy-neutral housing stock	Reducing the complexities of the work/process	Launched at the end of 2016
The Energy Saving Explorer - Three branch organisations for brokers and appraisers (Vastgoed-PRO, VBO Makelaar and NVM) - Developing an online tool, the energy saving explorer, with a 'cash value calculation' that enables valuers, brokers, banks and mortgage lenders to quickly calculate the potential energy savings that their customers could generate)	Reducing the complexities in applying loans/subsidies	Since 2017

Besides the policies at the national level, private or public-private parties, such as energy providers, start initiatives to enhance the energy efficiency in the building sector. For instance, in mid-2014, the Association of Dutch Municipalities (VNG)[4], supported by the Ministry of the Interior and Kingdom Relations, launched a programme aimed at accelerating and scaling up the energy efficiency of the private owner-occupied housing. All municipalities have committed themselves in 29 regions and worked together with companies and social parties on energy savings and energy generation in private homes. The plans of these regions have

4 1VNG cooperates intensively with umbrellas organisations (and private) associations such as Bouwend Nederland, Uneto-VNI, Netbeheer Nederland and VvE Belang, with partners such as Milieu Central and HIER Opgewekt. (https://vng.nl/regionale-aanpak-particuliere-koopwoningen.)

been summarised as the most crucial action points. The summary of these policy instruments, initiatives, and underlying hypotheses are presented here in Tables 2.1 and 2.2. The data are collected based on the energy agenda introduced by the Dutch cabinet at the end of 2016.

2.2.2 Behavioural aspects influencing the homeowner decision-making process

Drivers and barriers can be categorised as 'intrinsic' and 'extrinsic' factors. Intrinsic ones are the consequences of the interaction between an individual's internal wishes, ambitions, preferences, with their situations. Extrinsic factors can be the rules, financial costs and incentives, and so on [215].

The energy efficiency renovations (EERs) usually need high upfront costs compared to repairing/ improving the energy efficiency measures [418]. Monetary costs might be covered by homeowner saving, loans from families, friends, governments, or the banking system [215]. The banking system is a potential financial supporter and the interest rates influence the feasibility of renovations. Thus, an interest rate threshold exists and higher rates might demotivate the EERs [202, 215, 317].

Households perform renovations when they have the capabilities and expectation to achieve the potential benefits. The assumption is: an individual does not get involved in an action, either whenever it incurs high risks and/or the expected benefits are not favourable [215]. Factors that can be used to evaluate the homeowners' decision-making processes include: 1) bounded rationality, referring to the cognitive burden in collecting and processing information; 2) expected time and financial support to accomplish the renovations; and (3) expected faster return on investment, even though the renovations have long-term gains [147, 480].

Many research studies illustrate that the drivers and barriers to individual behaviours are more influential than monetary costs [228, 481]. Consequently, behavioural researchers aim to integrate more powerful psychological insights into the homeowner decision-making processes by considering a range of personal and contextual factors to explain the decision. Personal factors include cognitive awareness, attitudes and beliefs, experience, and skills, whereas contextual ones contain homeowner characteristics (e.g., size, composition, and number of children), socio-demographic variables (e.g., age, education, income, and employment), and property characteristics (e.g., construction period). To accomplish renovations requires advanced cognitive and emotional involvement on the part of homeowners

[32, 480, 481]. A recent study identified a strong differences in the adoption of energy efficiency technologies by income groups in eight European countries. Lowest income groups has less willingness to invest for all types of energy efficient technologies [396].

When individuals' basic needs are satisfied, they pursue safety, social engagement, self-esteem, and self-actualisation. For instance, pro-environmental behaviours are expected when a household has already achieved its basic needs and has the resources (time, money, and energy) to act generously. Some drivers, such as cost saving and thermal comfort, are more common in the applied behavioural and sociological research, and some, such as draughts, condensation, air quality, and property value, are occasionally mentioned [480].

Figure 2.1 explains different stages in the decision-making process. In general, the stages consist of understanding the needs, information searching, pre-evaluating, finalising the decision, implementing, and post-evaluating [32]. Renovations initially depend on the current conditions of life, and so the factors influencing the renovation decision change during the process. In the considering phase, the socioeconomic factors (e.g., education and income) are important when thinking and acquiring knowledge of renovations. In the planning phase, an awareness of the benefits can persuade homeowners to renovate [320,424, 478, 480]. In the planning and implementing phases, access to information regarding the methods and/or means in conducting the EERs is essential. After implementing and experiencing the EERs, the bad and/or good experiences are circulated through social networks and communication channels. The circulation of these feedback data also influence the next up-coming renovation processes for the users [481].

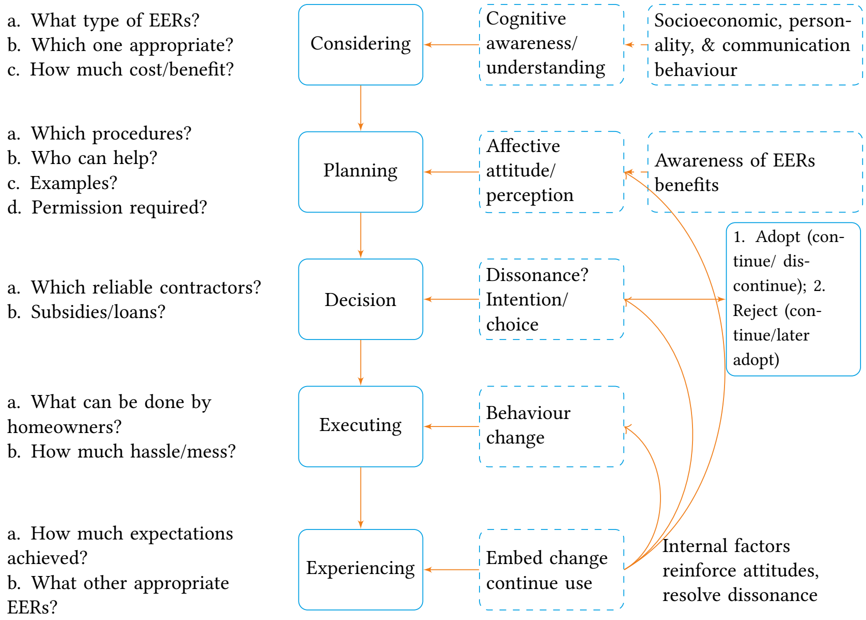

FIG. 2.1 Behavioural aspects influencing homeowner cognitive decision-making process (compiled from several sources)

2.2.3 Transaction cost factors as barriers in the decision-making process

Coase [80] defined a transaction cost (TC) as any indirect cost inevitable in producing goods and services, and essential in a transaction. TC negatively affects the renovation decision. Mundaca T et al. [316] interpreted it as a sub-category of 'hidden costs' that have not been adequately considered in the cost analysis. The determinants of TCs are shown in Figure 2.2, namely: asset specificity, uncertainty, and frequency. When an asset, such as physical/human, have been assigned for a particular purpose/ in a specific location/ for a particular agent, it generates additional costs since it cannot easily be used for other purposes [135]. These factors are essential in the considering and planning phases, since the homeowners need to evaluate the advantage of investment in a specific renovation type. Moreover, homeowners are responsible for renovations, and when they plan to do it themselves, they need to acquire specialised skills and knowledge before implementation. Two types of uncertainties are relevant: 1) uncertainty on the expected benefits; and 2) uncertainty arising from opportunistic behaviour. The latter occurs for instance because of lack of trust between parties including the professional contractors in executing renovation. When agents are doing more renovation projects, the uncertainties reduce because of the experience they have gained during the renovation process itself [135].

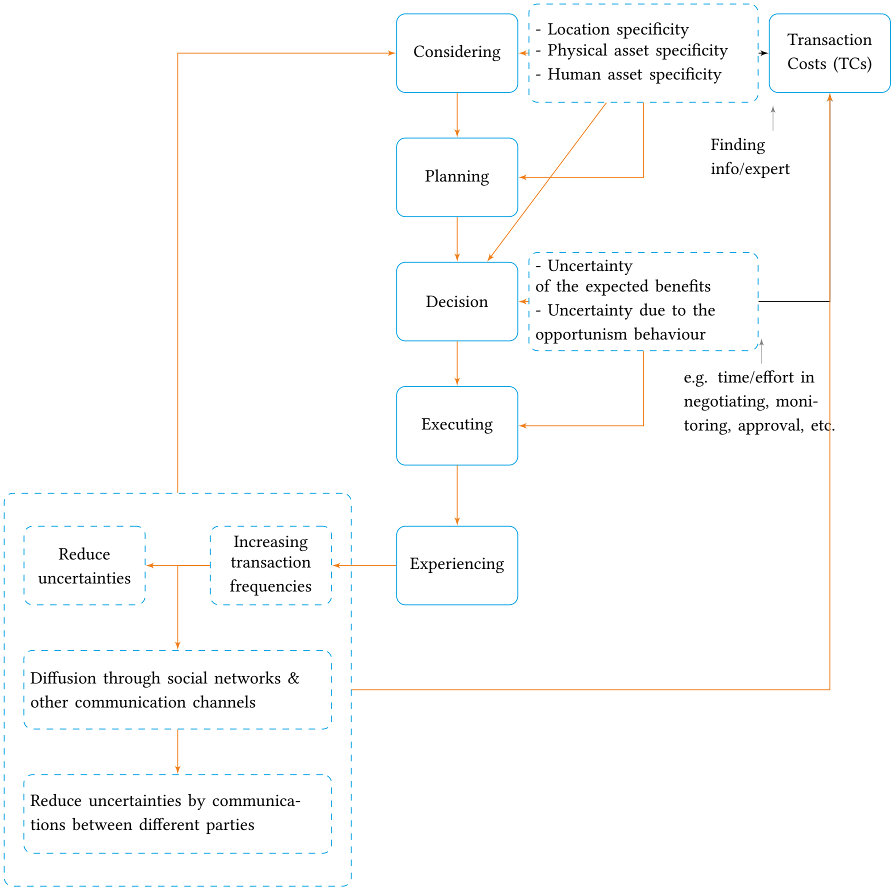

FIG. 2.2 Transaction cost factors influencing the decision-making process (compiled from several sources)

TCs also represent time and efforts to acquire knowledge and information. This type of TC is inevitable in energy renovations since information acquisition usually takes time and might be expensive [64, 213]. Additionally, the imperfect and asymmetric information might hinder the energy renovation since decision-makers encounter high costs to find reliable information [313]. Homeowners might not invest if they do not have the information regarding the nature and costs of energy efficiency renovations. Moreover, they are not usually educated in the basic construction technology, nor the construction industry and must find a way to learn or completely transfer the physical operations to an expert [424, 480]. The complexity in the decision-making process is also part of TCs: the cognitive burden of making complex and irreversible decisions, and the anticipated 'hassle factor' of having home-life disrupted during the renovations. Where an individual encounters difficulties to make proper and precise expectations, they might not invest optimally in energy efficiency renovations [202, 480].

2.2.4 Drivers, barriers, & determinants related to initiatives, behavioural, and transaction cost factors

Tables 2.3 and 2.4 summarise the influencing factors and determinants in energy efficiency renovations. These factors are categorised based on the initiatives by government, behavioural aspects and TCs. All the factors are explained in the last sub-sections (2.1-2.3).

TABLE 2.3 Drivers, barriers, and determinants regarding the initiatives and behavioural aspects form literature review

Category	Drivers	Barriers	Determinants
Initiatives	Promotion by public authorities	Lack of support by public authorities	-
Behavioural Aspects	**Financial benefit**	**Cost**	Age
	Cost-saving Increasing the house value Making the house easier to sell	Capital costs & Interest rate Uncertainly on energy costs/benefits & payback period	Education Income Employment Moved to a new house Household composition
	Enchanging the life quality	Delayed payoffs	Property features
	Repairing/replacing Equipment Increasing comfort Reducing noise		Number of people Cognitive Awarebess Attitudes & beliefs
	Environmental concerns		Experience & skills
	Protecting environment		
	Other's experiences		
	Following others		

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TABLE 2.4 Barriers and determinants regarding the transaction costs (TC) from literature review.

Category	Barriers	Determinants
Transaction cost	**Information barriers**	Asset specificity
	Time & efforts in finding info	Uncertainty
	Credibility barriers	Frequency
	Searching & finding reliable information and experts.	
	Self/support barriers	
	Lack of Time/effort in finding support & help.	
	Work/Process (W) barriers	
	Disruption in the ordinary life and anticipated hassle factor	
	Perceiving the EERs as not essential and a complicated process	
	Complexities in acquiring the knowledge & skills	
	Dissatisfaction of the past experience	
	Lack of Time/effort apply for loans/subsidies, doing the work	

2.3 Methodology

In subsection 2.3.1, the status of the Dutch housing stock is presented to give a general picture of the sector and the share of owner-occupied sector in the energy consumption. In subsection 2.3.2, the WOON 2012 energy module is described. The homeowner profiles and buildings features, the dependent and independent variables, and the limitation of the database are explained in this subsection. In subsection 2.3.3, the logistic regression including the pre-assumptions of running this model and validation are described.

2.3.1 Dutch dwelling stock and the owner-occupied sector

The owner-occupied sector has a considerable share about to 70% of the Dutch housing stock. The demand of owner-occupied houses has risen because of a more stable market and very low mortgage interest rates. The number of owner-occupied houses is estimated to increase by nearly 300,000 in the next five year period 2018-2022 [3]. Figure 2.3 shows the share of the owner-occupied and rental sectors during the period 2012-2017.

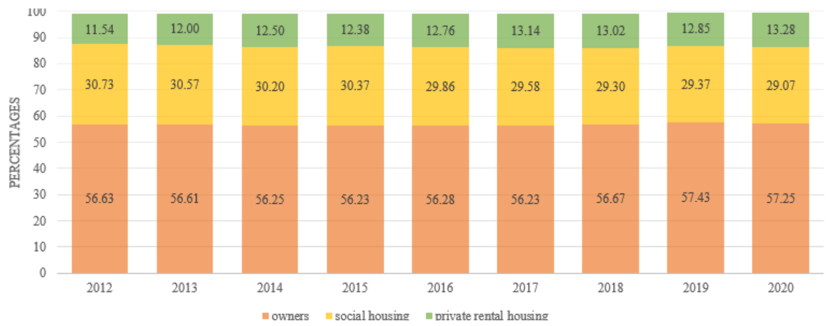

FIG. 2.3 Share of the owner-occupied and rental sector in the Dutch dwelling stock (CBS 2018)

A large amount of natural gas is consumed in the Dutch housing stock (almost 72% of total energy consumption [127]. However, in recent years, the average gas consumption is reduced mainly due to double glazing, high-performance boilers and better housing insulation [351]. Figure 2.4 shows the average gas consumption in the owner-occupied sector, rental and total dwelling stock. In 2017, the reduction in average gas consumption in the owner-occupied sector and rental sector, respectively, was equal to 16% and 22% compared to 2012.

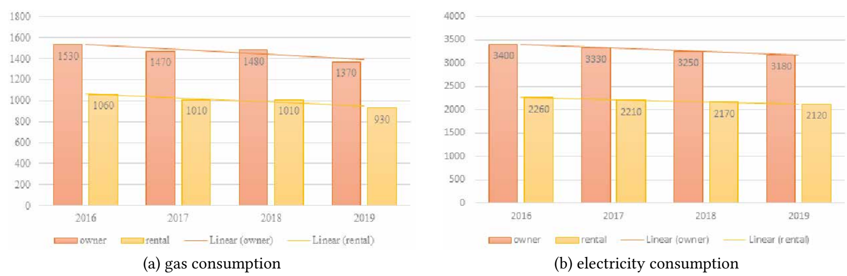

FIG. 2.4 Energy consumption in the owner-occupied and rental sectors [104]

2.3.2 WOON Energy Module Database

Dutch Ministry of the Interior and Kingdom Relations is responsible for carrying out a survey every 5-6 year about energy uses in rental and private building stocks as a part of a larger survey of Dutch dwellings (Woon – Woon Onderzoek Nederland, which stands for Housing Survey Netherlands). The survey is conducted among the households in the owner-occupied, social housing and private rental sectors. Besides the survey, other sources of relevant data collection are dwelling inspections and reports on energy consumption. The WOON database contains the details data on variables about occupant behaviour and more detailed data from the building inspections. In this study, the WOON2012 energy module, the most recent one, has been used. This database covers 4,800 houses in which 58% (2,784) are homeowners. Few researches evaluated the representative of the WOON2012 energy module for the Dutch housing stock [278, 372]. In the following sub-sections, the variables in the quantitative analysis are explained.

Households' Profiles and Buildings Features

Table 2.5 shows the Dutch homeowners' profile, such as 50% of homeowners are 54 years old/and more, and in 83% of the houses, only one family is living. Many of them are the determinants of the behavioural aspects.

TABLE 2.5 Profile of the Dutch homeowners

Homeowners' profile	Categories/Averages	Frequency	Percent
Age	17-34 year	348	12,5
(Four classes)	35-44 year	515	18,5
	45-54 year	605	21,7
	54 and older	1.316	47,3
Gender	Man	1.483	53,3
	Woman	1.301	46,7
Education	Lower-High school	1.520	54,6
	University degree	1.250	44,9
Income	41.484	2.744	98,6
(per year)			
Working hours	32,53	1.807	64,9
(per week)			
Moved in the past 2 years	No	2.562	92
	Yes	222	8
Total		2.784	100

The importance of building features are examined in many studies. These features explain 42% of energy consumption in the houses. Therefore, they are included in the regression analysis [144, 279, 391]. About 30% of the houses are row houses type. Detached houses, 2 houses-under-1-roof, and Maisonettes are ranked second and third in terms of numbers (see Table 2.6).

TABLE 2.6 Building Features

Building features	Categories	Frequency	Percent
One/multifamily	one	2.316	83,2
	more than one	468	16,8
Construction period	1945 and older	654	23,5
	1946-1990	1.369	49,2
	1990 and newer	761	27,3
Number of people in the house	1	604	21,7
	2	1.195	42,9
	3	343	12,3
	4	448	16,1
	5-8	194	7
Type of the building	Detached	562	20,2
	2 houses-under-1-roof	552	19,8
	Corner house	367	13,2
	Row house	761	27,3
	Maisonettes	462	16,6
	Other	61	2,2
Total		2.784	100

Figure 2.5 shows the distribution of dwellings based on the year of construction in the owner-occupied and rental sectors. The owner-occupied sector has the highest share in the very old and very new dwellings.

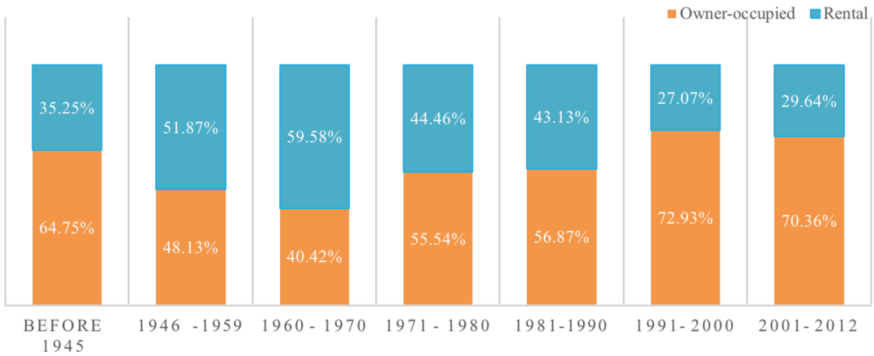

FIG. 2.5 Comparison of building year between owner-occupied and rental sector

Renovators and potential renovators

The WOON energie module 2012 contains questions with binary choices: a) Yes (1), b) No (0). We defined the renovators and potential renovators using the following questions:

1 **Renovators**, *Question 43 of the database: "have you installed insulation/double glazing in the past five years? "* In the database, there are 849 positive responses.

2 **Potential renovators**, *Question 59 of the database: Will you install insulation/double glazing in upcoming two years?* In the database, there are 338 positive responses.

Drivers to energy efficiency renovations

In the survey, series of questions are defined regarding the motivations. For instance, What does encourage them in doing/ planning for the EER - Was it 'cost savings on the energy bill'? The answers to the questions are (yes=1, or No=0). Therefore, the variables of drivers to energy efficiency renovations are binary. Based on the questions 43 and 59, we divided the database to calculate the frequency and percentage of positive responses for each driver (Table 2.7).

TABLE 2.7 Drivers towards energy efficiency renovations

Drivers	Frequency (%) (Renovators)	Frequency (%) (Potential Renova-tors)
Cost saving on the energy bills	558 (65.2%)	266 (78%)
Increasing the comfort	530 (62%)	211 (61.7%)
Protecting the environment	211 (24.7%)	134 (39.2%)
Improving ventilation	119 (13.9%)	55 (16.1%)
Increasing the house value	61 (7.1%)	39 (11.4%)
The boiler needed to be replaced	272 (31.8%)	29 (8.5%)
Reducing noise	90 (10.5%)	23 (6.7%)
Easiness to apply	102 (11.9%)	16 (4.7%)
Selling the house easier to sale	18 (2.1%)	9 (2.6%)
Following other people	5 (0.6%)	4 (1.2%)
VvE wanter to do it	4 (0.5%)	2 (0.6%)

Barriers to energy efficiency renovations

In the survey, a series of questions are defined regarding the hindrances. For instance, What does discourage them in doing/planning the EERs- Was it the time and effort in finding the information? The answers to the questions are (yes=1, or No=0). Therefore, the variables of barriers to energy efficiency renovations are binary. We divided the database to calculate the frequency and percentage of positive responses for each barrier (Table 2.8).

TABLE 2.8 Barriers toward energy efficiency renovations

Barriers	Frequency (%) (Renovators)	Frequency (%) (Potential R)
Cost of Energy Saving Measure	430 (50.3%)	203 (59.4%)
Limited/no subsidies	459 (53.7%)	201 (58.8%)
Time & effort: subsidies & Joans	427 (49.9%)	184 (53.8%)
Reliable professional	288 (33.7%)	117 (34.2%)
Reliable information	264 (30.9%)	108 (31.6%)
Time and effort: work	275 (32.2%)	109 (31.6%)
Knowledge and skills: work	272 (31.8%)	101 (29.5%)
Time and effort: information	216 (25.3%)	99 (28.9%)
Mess and nuisance: work	229 (26.8%)	81 (23.7%)
Expecting help from friend, etc.	153 (17.9%)	54 (15.8%)
Media report	29 (15,1%)	41 (12%)
Past experiences	91 (10.6%)	26 (7.6%)
Experiences of those around you	59 (6.9%)	13 (4.4%)

Limitations of the database

There are limitations in using the WOON energy module dataset:

1 The WOON energy module datasets are published only every 5/6 years due to high costs. The newest version is for 2012. The analysis would be more in line with the policy instruments by the newer version.

2 We aimed to investigate the whole process of decision-making process by householders. However, in the WOON energy module, the data is provided only for the main stages of implementing and planning. Therefore, we could not quantitatively analyse the overall process. It would be more comprehensive, if we had the information for other stages in the renovation process, such as considering phase, experiencing.

3 The dataset is not very clear in distinction of energy efficiency renovation and energy saving measures. In the WOON energy module, the question is designed in a way that includes both insulation, and the higher efficiency boiler, improved efficiency boiler, or solar water heater. Implementing some energy-saving measures cannot be considered as EERs. For instance, the decision of “Replacing a boiler (improvement/ repair)” is not comparable to “housing insulation (renovation)”. The second one needs a more complex decision-making process.

2.3.3 Method of Analysis

The impact of barriers and drivers are investigated, using logistic regression. In this regression, the probability of an event, occurring for randomly-selected observations are determined by any given combinations of independent variables [83]. Two separate regressions are estimated for the renovators and potential renovators. For the renovators, the dependent variable is the log of *Whether the respondents did a renovation in the past five years*. For the potential renovator, the dependent variable is the log of *whether the respondents are planning to do a renovation in the two upcoming years in the future*. By renovation, we mean the insulation or double glazing. By insulation, we mean the facade insulation, the internal and exterior insulation of the roof, the ground insulation, the attic, and other floors. By double glazing, we mean the double glass (HR++, no HR++, and type unknown), double glazing of the front windows, and others. The question also includes *whether the homeowners replaced the higher efficiency boiler, improved efficiency boiler, unknown type of boiler, or solar water heater*. In this analysis, explanatory variables are the social-demographic features, such as age, education, income, and the drivers, and barriers to EERs. In section 3.1.2 and 3.1.3, the drivers and barriers in the regression are specified.

Table 2.9 is an example of a logistic regression in Statistical Package for the Social Sciences (SPSS) (version 25.0). Coefficient B presents the changes in log of the dependent variable for every one-unit change in an independent variable. Odds ratios (column exp(B)) denote the degree of association between dependent and independent variables, and are used to compare the relative probabilities of the occurrence of the renovation, given the presence of the variables, such as households and building features, etc. Finally, A Wald test shows the significance of each coefficient in the regression.

TABLE 2.9 SPSS outcomes for logistic regression

Independent variables	B	S.E.	Wald	df	Sig.	Exp(B)
Constant						

The logistic regression has a few assumptions that need to be tested before running the regression software, including:

1 **Dependent variable is the log of the binary variables**

In the database, the original variable is whether they have done the renovation in the past five years or they are planning to do it in the near future in the upcoming two years. Therefore, it is binary (0,1). In the logistic regression, the dependent variable is logarithmic to make the coefficients easier to interpret and in percentages. For renovators, the dependent variable shows the probability of the renovation in the past, and for the potential renovators, the probability of renovation in the near future.

2 **The independent variables should not show multicollinearity**

In the logistic regression, the multicollinearity needs to be checked. Otherwise, the results are not reliable. To test the multicollinearity, examining the correlation matrix of explanatory variables might be useful but not adequate on its own. In this study, a more robust approach is followed, and multicollinearity is tested using the Variance Inflation Factor (VIF). VIF values of more than 10 are often considered as showing multicollinearity, and values of more than 2.5 is the initial point of concern [298]. For the implementation and planned regression, the highest VIF values are 2.397 and 2.115, respectively, and thus, this indicates acceptability regarding the multicollinearity in the analysis.

3 **The data should cover a large sample size** [353]

The sample size are sufficiently large. For the renovator and potential renovator regression, the sample sizes are 1946 and 689, respectively.

The model is specified as follows:

$$Log\left(\frac{P_{\text{renovation}}}{(1-P_{\text{renovation}})}\right) = X_{\text{households and buildings' features}} + X_{\text{sources of information}} + X_{\text{stages in help acquisitions}} \tag{2.1}$$

Where P is the probability of the events, and X represents independent variables, after estimation, the model is validated by the Omnibus tests of model coefficients and the Hosmer and Lemeshow test (Table 2.10). The Omnibus test shows whether the model predicts the outcome with the explanatory variables better than without [55]. The Omnibus tests are statistically significant, and, in this study dataset, the models show better results with explanatory variables than without. The Hosmer and Lemeshow test also examines the goodness of fit. The results of this test should not be significant to indicate a good model. Based on the tests, the regressions present reasonably good models. Additionally, Nagelkerke R Squares are equal to 0.423 and 0.385, accordingly.

TABLE 2.10 Assessing the two regressions regarding the goodness of fit

Stages	Omnibus Tests of Model Coefficients			Hosmer and Lemeshow Test		
	Chi-square	df	Sig.	Chi-square	df	Sig.
Renovators	320.904	20	.000	6.702	8	.569
Potential renovators	129.047	14	.000	8.355	8	.400

2.4 Results

First, the statistical analysis are shown to understand the overall ranking of the drivers and barriers, and then the significance of these barriers and drivers are presented according to the regression analysis.

2.4.1 Renovators

Statistical analysis

The rankings of the drivers and barriers are presented in the following sections. Additionally, the ranking of reliable sources of information, and who implements the energy efficiency renovation are presented.

1 Drivers

Figure 2.6 shows the renovator drivers towards EERs. Renovators have mainly aimed to achieve financial benefits and to enhance the quality of their life. More specifically, the main identified drivers are ‘Saving on energy bills’, ‘Improving comfort’, and ‘Increasing the efficiency of the boiler’. The least important ones are ‘Decision by homeowner association (VvE)’, ‘Following other people in the neighbourhood’, and ‘Selling house easier’. Considering the influence of VvE mainly for ‘More than one family in the same building’ and a small share of this category among the renovators (10%), the decision by VvE is among the lowest ranking.

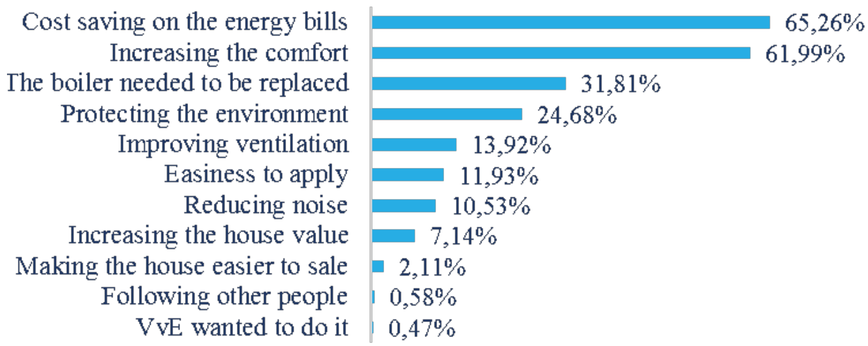

FIG. 2.6 The renovator drivers toward energy efficiency renovations

2 Barriers

The main identified barriers are ‘Limited/no subsidy’, ‘Costs of Energy Saving Measures (ESMs)’, and ‘Time and effort: apply for loans/subsidies’. The least important identified ones are ‘Experiences of those around the renovators, ‘Past experiences’, and ‘discouraging by Media’. The energy-saving measure cost is one of the main hindrances for the renovators, and as a consequence finding the financial support to cover it and complexities in applying for subsidies and loan are other vital barriers. 33.7% of renovators have affirmed that finding a reliable expert to carry out the renovations was a barrier (Figure 2.7).

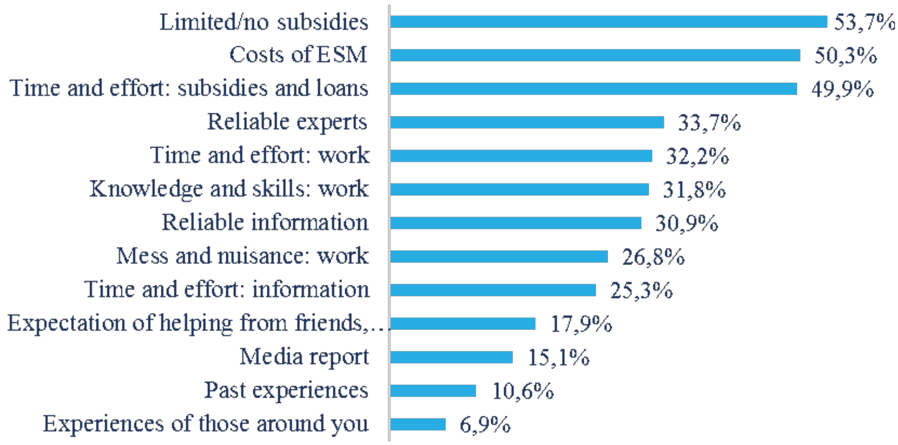

FIG. 2.7 The renovator barriers toward energy efficiency renovations

3 Reliability of information by different parties

The homeowners answered about the reliability of the information provided by different parties. The most reliable information is acquired through the homeowner association (VvE), the Dutch government and environmental agencies. The VvE data has been explored for one family and more than one family in a building. Overall, 56.5% (440) of one family and 62.2% (143) of more than one family in the same building confirmed the reliability of information by VvE (Figure 2.8).

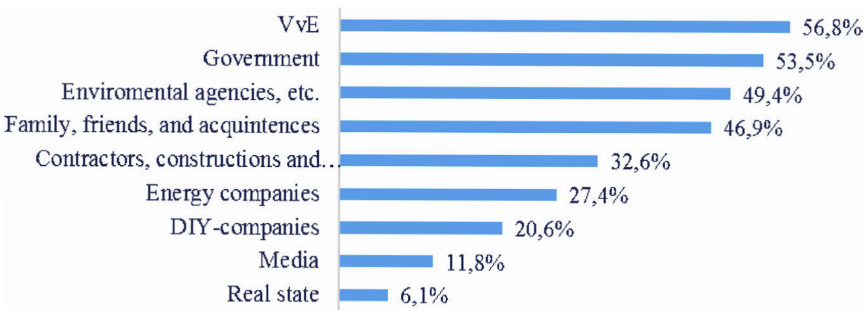

FIG. 2.8 The ranking of the reliable sources of information by renovators

Companies and experts mainly carry out the EERs for the renovators. About 35% of renovators have implemented the energy efficiency renovations by themselves/with help of acquaintances.

Regression analysis

Based on the results in Table 2.11, the coefficient of age, income, household types (one/more than one families), construction periods, and gender are statistically significant. The results show that the homeowners older than 35 are approximately 2.5 times more likely to renovate than the reference group (17-35). Regarding the type of family, the houses with one family are 2.7 times more likely to be renovated compared with multifamily houses, which indicates the complexity of renovation decision in multifamily buildings.

‘Gaining financial benefits’ and ‘Increasing the quality of life’ are the two main categories that are statistically significant. Respondents that have indicated ‘increasing comfort’ are 2.4 times more likely to have performed a renovation than respondents who have not indicated this driver. The other statistically significant drivers can be interpreted in the same way. Thus, respondents that have indicated ‘cost-saving on the energy bills’, ‘increasing the house value’, ‘reducing noise’, ‘improving ventilation’ are respectively about 1.4, 2.2, 3.1, and 2.7 times more likely to have performed a renovation. Protecting the environment, selling the house easier, the decision by VvE (mainly play roles in multifamily buildings), easiness to apply in the house are not statistically significant.

The main identified categories of barriers are ‘Programmes by the government’ and ‘Credibility of experts and information’. Among the variables of these categories, both ‘Limited/no subsidies’, ‘Lack of reliable expert’ are statistically significant. The ‘Reliable information provided by Do-it-yourself (DIY) companies’2 is statistically significant, although the other source of information has higher numbers of positive responses. Similarly, 38% of the respondents indicated ‘Reliable experts’ and 35% indicated ‘Reliable information: DIY-companies’ as barriers towards renovation. Although 58% of the respondents indicated limited/no subsidies as a barrier, 87% of the renovators paid themselves for the EERs. This might be due to the complicated and time-consuming process of acquiring subsidies by renovator, such that most of the renovators prefer to pay for EERs rather than applying for available subsidies.

The homeowners that renovate their houses by a specialised company/expert and themselves/ acquaintances are respectively 5.10 and 2.21 more probable to renovate their houses in comparison to the ones that did not implement the EERs by these agents.

TABLE 2.11 Logistic regression analysis for the renovators

Category	X	Y	B	S.E.	Wald	Sig.	Exp(B)
Socio-economic variables	Households & buildings features	Age			12.29	0.01	
		(35-44)	0.907	0.29	9.691	0	2.478
		(45-54)	0.981	0.3	11.04	0	2.668
		(54-older)	0.867	0.31	7.79	0.01	2.381
		Gender (1)	-0.42	0.18	5.642	0.02	1.52
		Multifamily	-1.01	0.29	12.03	0	2.739
		Construction period			98.85	0	
		(1946-1990)	1.068	0.21	26.86	0	2.91
		(1990-2012	2.678	0.27	98.85	0	14.56
		Income	-0.22	0.11	3.655	0.06	0.805
Drivers	Enhancing quality of life	Increasing comfort	0.879	0.17	25.45	0	2.408
		Reducing noise	1.047	0.43	5.906	0.02	2.848
		Improving ventilation	1.005	0.32	9.639	0	2.731
		Replacing the boiler	-0.83	0.19	19.01	0	0.438
		Cost savings	0.332	0.18	3.35	0.07	1.394
		Increasing the house value	0.803	0.44	3.304	0.07	2.232
	Programme by government Credibility of info/ expert	Limited/no subsidies	0.321	0.18	3.266	0.07	1.379
		Reliable experts	-0.49	0.19	6.937	0.01	0.611
		Reliable info: DIY C.	-0.6	0.2	8.804	0	0.547
	Work/Process	By me/acquaintances	0.794	0.29	7.648	0.01	2.212
		By a C./expert	1.628	0.31	28.46	0	5.094
	Costs	Costs of ESMs	-1.96	0.79	6.167	0.01	0.142
		Constant	0.765	1.12	0.467	0.21	2.149

2.4.2 Potential renovators

Similar analysis is conducted for the potential renovators. First, the statistical analysis is done to find out the overall ranking of the drivers and barriers, and then the significance of these barriers and drivers are investigated by regression analysis.

Statistical analysis

1 Drivers

Similar to renovators, ‘Gaining financial benefits’, ‘Enhancing the quality of life’, and ‘Environmental concern’ substantially motivate the potential renovators. More specifically, the main identified drivers are ‘Cost saving on the energy bills’, ‘Increasing the comfort’, and ‘Protecting the environment’. The potential renovators insist on ‘Cost saving on the energy bills” as the primary driver with the 78% votes. The least important ones are ‘Decision by homeowner association (VvE)’, ‘Following other people in the neighbourhood’, and ‘Selling house easier’ (Figure 2.9).

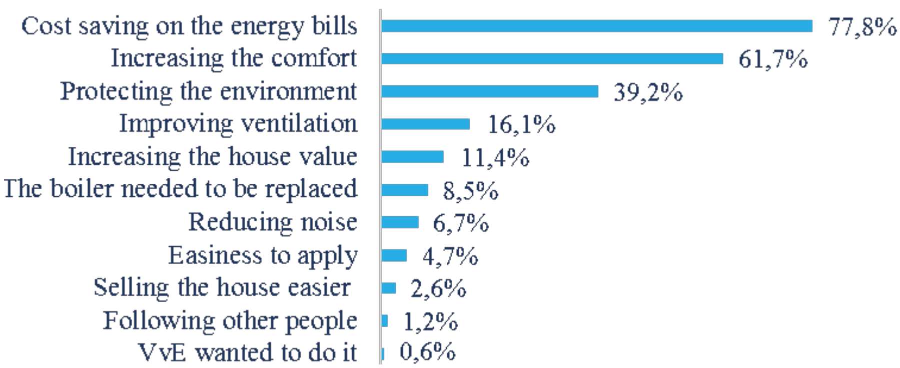

FIG. 2.9 The potential renovator drivers towards energy efficiency renovations

2 Barriers

The main barriers are ‘Costs of energy saving measures’, ‘Limited/no subsidy’ and ‘Time and effort: apply for loans/subsidies’. The least important barriers are ‘Other homeowners’ experiences’, ‘past experiences’, and ‘discouraging by Media’ (Figure 2.10).

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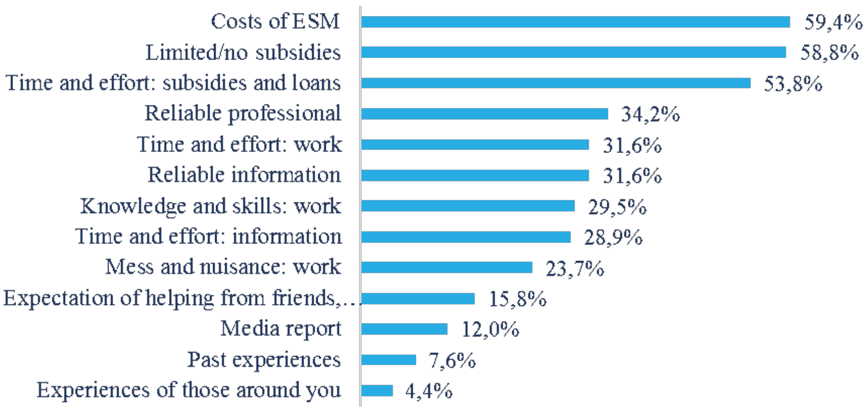

FIG. 2.10 The potential renovator barriers towards energy efficiency renovations

3 Reliability of information by different parties

The most reliable information has been stated the homeowners' association (VvE), the Dutch government and environmental agencies. Regarding the information provided by VvE, 64.2% (199) of one family and 65.6% (21) of multifamily in the same building confirmed the reliability of information by VvE (Figure 2.11).

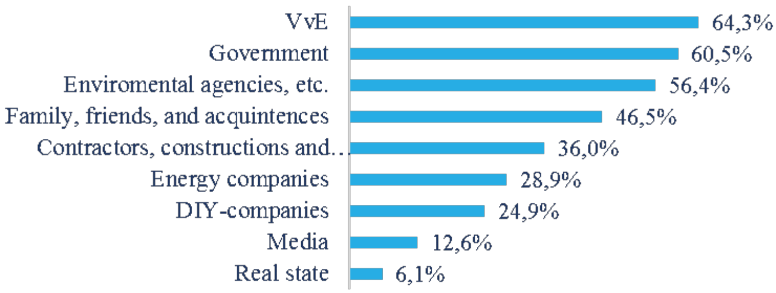

FIG. 2.11 The ranking of reliable sources of information by potential renovators

4 **Implementing energy-saving measures**

About 64% of potential renovators have planned to carry out the EERs by transferring to a company/ an expert. 36% have aimed to do it themselves.

Regression analysis

Based on the results, type of households, income, and ‘Moved in the past 2 years’ are statistically significant (Table 2.12). Regarding the drivers, ‘Improving the quality of life’ and ‘Gaining financial benefits’ are the two statistically significant categories. Furthermore, the significant categories of barriers are ‘Information’, ‘Credibility of information/expert’, ‘Complexities in work/processes’ and ‘Costs’.

Households that moved in the past 2 years are 2.3 times more likely to renovate than the ones who did not. Respondents that have implied ‘Increasing comfort’ and ‘Improving ventilation’ are 4.2 and 3.6 times more likely to plan renovations than the ones who have not indicated this driver. The ‘Time and effort: information’, ‘Reliable information: government’, ‘Work done: myself/ acquaintances’, ‘Costs of ESMs’ are stated as a barrier by 63%, 69%, 68%, 62%, respectively, of potential renovators who will do renovation, respectively.

TABLE 2.12 Logistic regression analysis for the potential renovators

Category	Main	Y	B	S.E.	Wald	Sig.	Exp(B)
Socio economic variables	Households & buildings features	Household composition			7.634	0.02	
		Couple (1)	-1.17	0.45	6.701	0.01	0.312
		Couple children (2)	-1.13	0.43	6.902	0.01	0.323
		Income	0.598	0.32	3.614	0.06	1.819
		Will move	0.847	0.43	3.903	0.05	2.332
Drivers	Enhancing quality of life	Enhancing comfort	1.38	0.25	29.55	0	3.976
		Improving ventilation	1.813	0.52	11.98	0	6.127
		Boiler replacement	-1.33	0.34	15.04	0	0.264
	Financial Benefits	Increasing house value	1.057	0.48	4.925	0.03	2.877
Barriers	Info	Time and effort:	0.525	0.3	3.093	0.08	1.69
		information					
	Credibility of info/ expert	Reliable information:	-0.62	0.35	3.098	0.08	0.538
		environmental agencies					
		Reliable information:	0.802	0.33	5.925	0.02	2.231
		government					
	Work /Process	Mess & nuisance: work	-0.54	0.31	3.027	0.08	0.585
		Will be performed	0.723	0.29	6.28	0.01	2.061
		by myself acquaintances					
	Costs	Costs of ESMs	0.494	0.26	3.566	0.06	1.639
		Constant	-9.3	3.25	8.187	0	0

2.4.3 Significant factors of the renovators and the potential renovators regarding the renovation decisions in the regression analyses

Table 2.13 summarises the significant factors in the renovator and the potential renovator regressions. In the discussion, the differences in the renovators and potential renovators' influencing factors are discussed.

TABLE 2.13 Significant factors for renovators and potential renovators regarding the decision-making for renovations

Factors	Renovators	Potential renovators
Socio-demo-graphic Factors	**Household & building features:**	**Household & building features:**
	- Household types	- Household types
	- Income	- Income
	- Age	- Construction period
	- Gender	
	- Construction period	
Drivers	**Enhancing the quality of life**	**Enhancing the quality of life**
	- Increasing comfort	- Increasing comfort
	- Improving ventilation	- Improving ventilation
	- Boiler replacement	- Boiler replacement
	- Reducing noise	
	Gaining financial benefits:	*Gaining financial benefits:*
	- Cost savings	- Increasing the house value
	- Increasing the house value	
Barriers	**Cost of energysaving measures:**	**Cost of energysaving measures:**
	- Costs of ESMs	- Costs of ESMs
	Program by government:	**The Credibility of info/expert:**
	- Limited no subsidies	- Reliable info: environmental agencies
	The Credibility of info/expert:	- Reliable info: government
	- Reliable experts	**Work/Process:**
	- Reliable information:	- By myself/acquaintances
	- DIYcompanies	- Mess and nuisance: work
	Work/Process:	**Information barriers:**
	- By myself/acquaintances	- Time & effort: information
	- By a company/expert	

2.5 Discussion of Results of Statistical and Regression Analysis

2.5.1 Comparison of two groups: renovators and potential renovators

This study has attempted to investigate the barriers and drivers of two groups; the renovators and potential renovators through regression analyses. The key difference between these two regression analyses are on the drivers and barriers:

1. The main identified categories of drivers are ‘Enhancing the quality of life’ and ‘Gaining financial benefits for both groups. These drivers are similar to the study by Aune [24] and Mlecnik and Straub [309]. The main identified categories of barriers are ‘Lack of reliable expert and information’, ‘Complexities in carrying out the renovations’ and ‘Cost’ for both groups. Additionally, ‘Lack of financial support from public authorities’ is identified essential for renovators and ‘Information barrier’ is identified significant for potential renovators.

2. The insignificant categories of drivers are ‘Technical benefits’, ‘Environmental concern’, ‘Experiences of other people’ for both groups. The insignificant categories of barriers are ‘Past experiences’ and ‘Lack of support and help from family, friends, and acquaintance’ for both groups.

2.5.2 Insights from behavioural and transaction cost factors

The behavioural and transaction cost factors are important in the homeowner renovation decision. Firstly, the behavioural aspects directly influence the renovation decision. The cognitive awareness, which can be determined by the decision-makers features, such as age, and education. Based on the findings of earlier studies, the consumer behaviours are predominantly determined by cognitive biases, heuristics and other irrational variables. For example, finding an alternative to reduce complexity, consumers prefer greater certainty over higher risk with higher values, and when faced with a decision, they are strongly dependent on the people around them.

TCs explain the indirect costs due to the transactions with external parties or distribution channels, for instance, to find information, experts, etc. In the analysis, transaction cost factors are categorised into: a) Time and effort to find information, to apply for loan and subsidies, and to conduct the renovation; b) Difficulty in finding reliable information and experts; and c) Complexities in acquiring knowledge and skills for renovation and disruption of normal life during the renovation.

The influencing factors determine the renovation process at different stages. The socio-demographic factors (e.g., age, income, education) are more critical in the initial stages. For example, it might be easier for educated people to acquire the required knowledge, and skills to execute the process or higher income group has more possibility to invest in EERs [396]. The drivers (e.g., enhancing comfort) play roles in the persuasion phase and of changing the perceptions of homeowners regarding EERs [320, 424, 478].

TCs hinder the EER processes at different stages. Initially, asset specificity is essential, while in later stages, the uncertainties in the decision-making process, such as the expected benefits and, finding reliable information, and expertise, all influence the renovation decision. Given better conditions to reduce these uncertainties, whether or not homeowners have experiences in energy-efficiency renovations, the uncertainties and the transaction costs decrease. The importance of these factors are identified using the statistical and regression analysis:

1. Based on the statistical analysis, the monetary costs, lack of subsidies and loans are the most important barriers. The time and effort to apply for subsidies is the third important barrier. Therefore, it can be concluded that the financial factors are the most important barriers for the renovators and potential renovators. Beside monetary costs, the TCs are also identified as determining barriers (e.g., Difficulty in finding reliable expert and information, time and effort in conducting the work and finding information).

2. Based on the regression analysis, the lack of reliable experts and information, time and effort to find information, and complexities in work/ process are all identified as critical influencing factors in renovation decision.

2.5.3 Insights for policies and private/ public-private initiatives

Table 2.14 shows the barriers and drivers that are included in the policies and private/ public-private initiatives. Based on the Table 2.14 and comparing it with Tables 2.3 and 2.4 (barriers & drivers), the essential policies and other initiatives are covered to facilitate the renovation process in the Dutch owner-occupied sector, such as providing the financial support, helping homeowners to find reliable energy providers. The findings are similar to those in the previous studies by Murphy,et al [319] and Tambach, et al [431].

TABLE 2.14 The Dutch policies & initiatives addressing the barriers & drivers

Underlying hypothesis	Barriers & drivers
Providing financial supports	Financial drivers
Informing advantages of renovations	Aiming at all drivers
Removing the current obstacles and barriers	Aiming at all barriers
Informing in using more efficient material	Information & cost barriers
Helping in finding reliable energy providers	Reliable experts
Reducing the complexities by new approaches, applying for loans/subsidies	Work/process barriers

The following policies implications require attention:

The results of the statistical and regression analysis (section 4) have shown the importance of the trans- action cost barriers. Referring to Table 1 and 2 on the existing policies, there are fewer policy programs that focus on eliminating these types of barriers compared to for instance policies that are focused on financial barriers. Lack of reliable information is also one of the main barriers. Based on the statistical analysis, about 30% of homeowners have stated the importance of this barrier and this factor also was significant in the regression analysis. This means that policy instruments especially should aim at tackling these types of barriers. In this respect it is not only important to provide homeowners with reliable and tailor-made information about solutions and their effects (possible savings and comfort improvements, but also to support and guide them throughout the renovation process (including finding a loan or subsidy and a contractor and installer).

Current and newly emerging policy instruments in the Netherlands contain interesting ingredients to overcome the barriers mentioned above. The ‘Energy Saving Explorer’[5], developed by energy providers, is a good example. Also, many Dutch municipalities (more than 200) have installed energy desks (energieloket.nl) where homeowners can get information and tailor-made advice about the ways the energy efficiency and the comfort of their dwellings can be improved. Municipalities, construction companies and installers often collaborate and join forces in the energy desk initiatives so that homeowners also can get practical advice about technical measures and products in an accessible way.

Other interesting developments in this regard are the deployment of one stop shops or pop-ups to create awareness and to support homeowners during the process to improve the energy performance and comfort in their dwellings. These initiatives can not only be found in a growing number of Dutch municipalities, but also in neighbouring countries [292].

These one stop-shops could pop-up in certain specific neighbourhoods and could also address the specific needs and wishes of individual homeowners. Although the lack of awareness, the absence of sufficient knowledge and information and the lack funding can generally be seen as the main barriers to undertake energy efficiency measures. Every homeowner is also confronted with its own individual and personal barriers that largely are related to their household, and dwelling characteristics and their personal beliefs and convictions. The first experiences of pop ups in Dutch cities such as The Hague and Rotterdam show that the communication via one stop shops and pop-ups could have influence on the decision-process of the homeowners. Subsequently the homeowners are supported throughout the complete process to improve the energy performance and comfort levels of their dwelling.

5 The aim is to calculate the potential energy saving of householders by the financial support system.

2.6 Conclusions and Policy Implications

The current study contributes to identify the drivers of and barriers to Energy Efficiency Renovations (EERs), including an empirical analysis of Dutch homeowners' decision-making processes. The theoretical analysis categorised the influencing factors into: policies and private/ public-private initiatives, behavioural factors, and transaction cost factors. The household renovation decision is complex and in this study, the aim was to explain the decision by using the main influencing factors derived from behavioural research. If the main behavioural aspects could be identified, the householder behaviour can be influenced by designing more comprehensive policies covering all these factors. Both the policymakers and practitioners often neglected these aspects when attempting to stimulate the energy efficiency renovations. The Transaction costs (TCs) can negatively affect the performance of policy instruments which aim to promote energy efficiency renovations [316]. The policies and initiatives, such as the energy saving explorer, One-stop-shop, and energieloket, can contribute in reducing the TCs.

After demonstrating the influencing factors, the relative importance of these factors was investigated using a regression analysis in the Dutch owner-occupied sector. The following policies are recommended to facilitate the upscaling of EERs both in terms of more renovators and deeper types of EERs:

1. Enhancing the quality of life (e.g., increasing thermal comfort) is a more important factor in the householder decision-making processes (e.g., the renovators who chose "Increasing comfort" were 2.4 times more likely to renovate compared to those who did not choose this specific driver.). The policies should be designed so as to increase the awareness of householders regarding the impacts of EERs and their direct influence on the quality of their life in terms of comfort, and improving health conditions by better ventilation, and by reducing condensation.

2. Based on the statistical and regression analysis, limited/ no subsidies and the costs of EERs were identified as significant and very important barriers. A huge amount of financial supports are provided by the Dutch government (e.g., the National Grant Scheme More with Less [102]. However, the lack of financial supports are still perceived as an important barrier for the householders. The issue can be connected to other obstacles (e.g., complexity in applying for loans/ subsidies, householders unawareness, and the unequal distribution of the subsidies and grants among householders). Therefore, in assigning the grants and subsidies, the policy makers might consider complementary policies, such as comprehensively informing the

householders regarding the availability of loans and subsidies, and reducing the complexities in accessing subsidies and loans.

3 The outcomes regarding TC barriers, e.g. reduction of information barriers, reliability of experts and information could be very useful for the policy-makers. The time and effort spent in finding information, and the reliability of information and experts were identified significant and important barriers. Policy-makers might need to invest more on provision of information and connecting the right information hubs and agencies to the householders. Additionally, the main reliable sources of information were identified (e.g., homeowners' associations and environmental agencies). The policies might consider these agents in distributing information.

4 The current Dutch policies need to take all of the relevant factors into account, such as reducing complexities in the process, reducing the time needed to apply for loans and subsidies, and facilitating access to information. The similar results are concluded to a study in Germany [32] in which homeowners also used several decision-making criteria that diminish the importance of monetary factors. Besides that it is important to rethink what should be the best way homeowners could be reached, approached and supported. It is in this respect predominantly acknowledged that, instead of a common national policy approach, an approach is needed that is based on the local level (e.g. in municipalities and its neighbourhoods). A policy that aims to change the individual behaviour of owners should after all take into account the requirements, needs and abilities of these homeowners.

5 Whether the policy-makers use the outcomes of this paper is also important. More householders might have actual willingness to renovate their houses towards more efficiency, but only if they are fully aware of the help on offer. Additionally, whether the benefits and consequences of different renovations, such as the insulation of the facade, are made clear to the householders, it might lead to a deeper consideration of energy efficiency renovations.

3 Behavioural factors: contextual, personal, and motivational factors

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Note: Chapter 2 clarified the importance of behavioural factors of the decision-making process of energy efficiency renovations. The main emphasis was on contextual (e.g., building characteristics), and motivational (e.g., improving comfort) factors for overall energy efficiency renovations. Still, many behaviour influencing factors are essential to be examined. Chapter 3 examines the behaviour-influencing factors for four types of energy efficiency renovations: double-glazing, insulation, solar PV panel, and sustainable heating system. It aims to fill in the gap of the literature by developing a theoretical framework that includes different categories of behaviour influencing factors. Then, the importance of different behaviour-influencing factors are investigated for four types of energy efficiency renovations. In addition to contextual and motivational factors, this chapter examines the impacts of personal factors including the perception of households on energy consumption, whether they have consciously reduced their energy consumption, whether they have consciously replaced the non-energy efficient devices with the energy efficient devices. The Netherlands energy module 2018 lies on the basis of these analyses. This dataset contains the data of 2,878 homeowners.

ABSTRACT

Over half of all residential buildings in the Netherlands are owner-occupied. In this study, the influence of behavioural factors on individual decisions toward Energy Efficiency Renovations (EERs) was investigated. This study focused on contextual (e.g., building characteristics), personal (e.g., awareness of energy consumption), and motivational factors (e.g., improving comfort). Logistic regression analyses were selected as the preferred method of analysis. The Netherlands's housing survey energy modules, which was conducted in 2018, was the basis of these analyses. 2878 homeowners were surveyed. Behavioural factors that influence the homeowners' decisions were investigated for four types of EERs: (1) double glazing, (2) insulation, (3) photovoltaic (PV) panel, and (4) sustainable heating. It was found that homeowners' preferences for double glazing were mainly influenced by the characteristics of the building and household and motivation to adopt EERs. Similarly, insulation and PV panels were to be mainly influenced by building characteristics. For sustainable heating, a combination of building and household characteristics and personal factors (e.g., deliberate gas reduction) influenced the decisions regarding this EER. None of the personal factors had a significant impact on the decisions regarding installation of double glazing; in contrast, the installation of PV panels was found to be highly influenced by these factors.

KEYWORDS Energy Efficiency; Renovation; Behaviour-influencing factor; Contextual factor; Personal factor; Motivational factor; Residential sector; Owner-occupied sector; The Netherlands

3.1 Introduction

In the Paris Climate Agreement (2015), nearly two hundred countries agreed to reduce global warming to within 2C of pre-industrial levels. Buildings contribute about 25% of direct and indirect global greenhouse gas (GHG) emissions. Building sector can substantially mitigate GHG emissions through large-scale energy-efficient renovations and using renewable energy sources [209, 388]. The Netherlands is set to reduce GHG emissions by 49% by 2030 and by 95% by 2050 relative to the 1990 baseline [175]. Furthermore, other targets such as producing 67% of total electricity from renewable sources by 2030, and fully climate-neutral electricity by 2050 are mentioned in this agreement. Recent studies have cast doubt on whether these targets will be achieved based on the current trends of GHG emissions [63, 352]. To achieve these targets, the amount of GHG emissions that needs to be eliminated in the next 10 years is twice as much as has been eliminated in the last 30 years. These uncertainties are obvious for targets that specifically focus on the residential sector, such as making existing houses gas-free by 2050. The plan is to reach this target by making 30 to 50 thousand houses gas-free per year at the beginning, and to gradually increase this number to 200 thousand per year. However, such a fundamental change demands significant modifications at the infrastructural level, which are quite difficult to realise. Adapting energy efficiency renovations (EERs), such as highly insulated buildings, appears to be a more realistic measure for moving towards these targets [176]. The Dutch government is attempting to reach the target by providing subsidies and loans for different types of renovations while actively informing households about ways to save energy, relevant implementation approaches, and the availability of financial incentives [438, 439].

In the Netherlands, quite a limited number of new dwellings have been built since 2012. The total housing stock consists of 1% of houses newly added within the year [414]. Accordingly, the renovation of existing dwellings seems to be the most viable solution for realising the energy efficiency targets [377]. Recent studies on this topic suggest that cost-savings and increasing comfort are the main reasons for starting EERs, while households tend to pay less attention to the energy efficiency aspects of renovation. Therefore, EERs should be promoted together with other maintenance/renovations [342, 478, 480]. In addition to motivations, the rates for different EERs are determined by different contextual factors that influence, such as building and household characteristics, and personal factors, such as attitudes and perceptions about energy consumption. More importantly, recent research has identified cognitive biases of the category of personal factors as an important barrier to EERs [88, 242, 427, 478]. However, empirical research into the exact nature of the cognitive biases and the effectiveness of interventions to de-bias are lacking.

The determined behaviour-influencing factors were different for different sub-sectors [88, 113, 217]. For instance, homeowners are most likely to perceive difficulty with finalising decisions, purchasing energy efficiency measures, and finding subsidies. On the other hand, tenants are most likely to perceive difficulty with the installation process [88]. Despite the recent attention, our understanding of the impact of behaviour-influencing factors on EERs is limited. Oversimplifying occupant behaviour and neglecting behaviour-influencing factors in designing energy policies may lead to inadequate results [203]. Yet, this information is vital for policymakers in designing and implementing policies that are effective in reducing the energy consumption of housing stock. As most houses in the Netherlands belong to the owner-occupied sector, further studies are essential to identify the behaviour-influencing factors and their impacts on EERs in this sub-sector. In the building sector in the Netherlands, energy transition policies are designed to allow converting entirely to renewable energy resources. These policies include: 1) near-zero energy indicators for new buildings; 2) large-scale energy renovations for a lower Energy Performance Certificate (EPC)-Levels (D and F); 3) subsidies for heat from renewable sources, more use of solar photovoltaic (PV); 4) raising awareness about renewable energy resources, and 5) switching to electricity for energy [458].

This study aims to evaluate the main behavioural factors that influence different types of EERs, and to examine whether current EER policies can be improved by considering the impacts of these behaviour-influencing factors. More specifically, the personal, contextual, and motivational factors that influence the decision-making process of EERs are studied in the Dutch owner-occupied residential sector. To date, most existing studies have limited their focus on a single technology, based on the literature review done in Camarasa et al. [71]. In this study, four types of EERs are investigated, namely 1) double-glazed windows; 2) insulated roofs, walls, and floors; 3) solar PV panels; and 4) sustainable heating systems. These types of EERs comprise the highest percentages of total EERs that used the Netherlands housing survey energy module 2018. In addition to this, based on the literature review, the impacts of reducing energy consumption and improving comfort, and the environmental benefits were the most compared with other EERs [198, 386, 449, 463]. Figure 3.1 shows the distribution of energy efficient measures conducted by Dutch homeowners in 2018. Among these measures, double glazing has the highest percentages (20.2%), and sustainable heating is the second, with 15.2% of houses. Appendix 1 explains the advantages of installing energy efficiency measures for residents and dwellings.

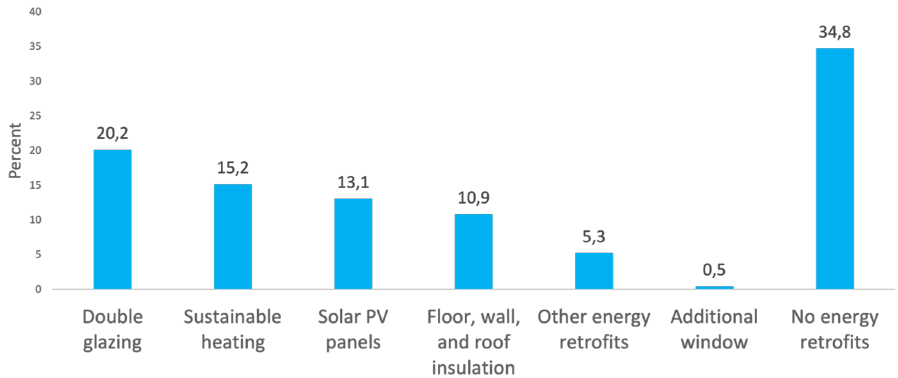


FIG. 3.1 The percentages of renovators that have used different energy-saving measures (34,5% of households use no-energy-saving measure)

The developed theoretical framework is validated using logistic regression analyses and empirical data from the Netherlands housing survey energy module 2018 for renovators and potential renovators. The energy module 2018 was conducted on a representative sample of Dutch housing stock. This dataset contains valuable information on household and building characteristics. In addition to these variables, the energy and investment behaviour of households, such as the perception of energy consumption compared with other households, are also provided. Moreover, the information regarding whether the household performed any EERs in the past five years and whether the household is planning to implement an EER in the next two years is stored in this dataset. The main contributions of this research are as follow: (a) Empirical investigation of the cognitive biases and the impacts of the other personal factors, such as the perception of households on energy consumption compared with others, using logistic regression. (b) Identifying which behaviour-influencing factors influence the homeowners' renovation decisions for double glazing, insulation, PV panels, and sustainable heating using logistic regression analyses.

3.2 Literature review on policy interventions and behaviour-influencing factors

3.2.1 Policy interventions for the owner-occupied sector

Steg and Vlek [420] categorised policy interventions that influence human behaviour into structural and informational interventions. Structural interventions modify the conditions in which households make decisions, such as financial incentives (e.g. subsidies, tax) and provide access to energy efficient technologies. Informational interventions influence people's motivations, such as providing information with respect to energy-efficiency technologies and social norms on energy savings, as well as feedback on these topics [5, 390]. Information provision is most commonly used to motivate households to reduce their energy consumption. This category of interventions can be classified into antecedent and consequent interventions. The latter, e.g. labelling, mainly influences the determinants of behaviour, e.g. knowledge and motivation. The former aims to provide the information after the behaviour has been carried out, e.g. feedback provision [203].

There are many examples of structural interventions in the approach taken by the Dutch government. Currently, 95% of houses use natural gas for heating, hot water, and cooking in the Netherlands. Despite this considerable share, the Dutch government has assigned specific budgets to eliminate natural gas as a source of energy by 2050. Consequently, €435 million has been allocated to natural gas-free neighbourhoods[6] between 2018 and 2028 [176]. Table 3.1 shows the Dutch policy interventions in motivating homeowners to make EERs [104, 210, 222, 299, 330, 438, 439]. Among these measures, insulation and PV panels are the focus of attention by local authorities. For ISDE subsidies, the amount requested by the entities (homeowners and companies) were approximately twice as much as the planned budget in 2019.

Subsidies, loans, and taxes are examples of supply-side policies in the market. Other countries provide similar support, such as low interest rates, third-party financing, payment on energy bills, energy efficiency mortgages, and crowdfunding [43, 45, 236, 480]. Flanders, France, Italy, the United Kingdom, and Poland offer energy efficiency obligation programs, in which energy suppliers must provide evidence of contributing energy savings by promoting energy efficiency activities or financial support for residents [45, 236]. The Green Deal in the United Kingdom was an example of financing by a third party and paying back on energy bills. However, this program was not successful in up-scaling EERs (with the goal of one million houses). The reasons were that there was no guarantee of energy savings, the process was complex and bureaucratic, the interest rates were above the mortgage rates, and financial savings were the only objective, rather than households' comfort and well-being [43].

6 In 2018, the Dutch government selected 27 neighbourhoods, at least one per province, to support in removing gas as a source of energy. In this program, the dwellings are renovated by a combination of good insulation, economical installations for heating and hot water, and the use of renewable energy sources [176].

TABLE 3.1 Main Policy Interventions in the Netherland

Policies at national level	Energy Efficiency types	Subsidies	Loans
Save energy now In Dutch: Energie besparen doe je nu 2017-2020	Subsidies/loans: - Insulation of roof, facade, cavity wall, floor, and windows (at least 2 measures) - Solar water heaters - Heat pumps - Ventilation with heat recovery - PV panels	- Insulation: 20% of costs - Heat pump depends on type and household budgets € 1,300 – 3,400 - Solar water heater: depends on the size, e.g., 1,100 euros for a solar boiler For 4 people - PV panels: reclaim VAT e.g., 10 PV panels = € 4,400 reclaim Money = 750 euros	Max € 65,000 per entity Interest rate: - Households 1.7% - homeowners associations with: 1.9%
Energy saving owner-Occupied sector In Dutch: Subsidie energiebesparing eigen huis (SEEH) 2019-2020	Subsidies - Main: at least two insulation measures - Complementary energy saving measures (door insulation, etc.) - Highly energy efficiency packages (roof, facade, etc.)	Since 19 August 2019 and will be available after 2020 € 84 million Normal: max of € 10,000 HEEP: max. of € 15,000	-
Sustainable energy investment grant 2020 In Dutch: Subsidie voor duurzame energie (ISDE)	Subsidies - Heat pump - Solar water heater	- Heat pump € 500 and € 2,500 - SWH: € 500 Total budget: € 100 million	-
Insulation of homes 2020	Insulation materials: glass wool, rock wool. styrofoam, glass (insulation), polyurethane	- Buildings older than 2 years: tax exemption of 9% VAT labour costs instead of 21%	

Complementary to these policies, the national environment centre (In Dutch: Milieu Centraal) influences householders' motivations through informational interventions. This centre provides information on all the possibilities for an energy-efficient and sustainable house, the availability of subsidies and loans, the steps to becoming natural gas-free, and finding a professional/company, etc. Accessing information does not solely result in a change in behaviour because people often make choices based on mental shortcuts and habits [262].

To enhance the effectiveness of information provision, the role of social norms has been investigated by several researchers. For instance, from five groups of households having different information interventions, namely (1) save money by conserving energy; (2) protecting the environment by conserving energy; (3) conserving energy for future generations; (4) joining neighbours in conserving energy; and (5) saving energy by using fans instead of air conditioning, group (4) achieved the highest electricity savings. The reason for that is the inclusion of social norms in information provision [432].

Informational feedback on energy consumption is considered a low-cost strategy for saving energy. This type of intervention has gained increasing attention due to the advancement of information technologies and energy infrastructures. The effectiveness of this behavioural change has been examined in many countries within and outside Europe [25, 136, 155, 259, 271, 285, 404]. According to previous studies, the provision of information through in-home displays (IHDs), WeChat, and smart meters diminished electricity consumption by approximately 20%, 16%, and 11–17% compared with houses without this information in the Netherlands, China, and Northern Ireland, respectively [25, 155, 404].

3.2.2 Behavioural factors that influence homeowner renovation decisions

Behaviour depends on individuals and their environment. The factors that influence human behaviour can have multiple origins and can be categorised as: motivations (e.g. thermal comfort); barriers (e.g. information); contextual factors; personal factors. Wilson, et. al., [480] reviewed behavioural studies on energy efficiency to identify the factors that influenced on homeowner renovation decisions. An example of personal factors is the way individuals evaluate information. Individuals usually evaluate information based on their own perceptions to make decisions [163]. For instance, the energy efficient measures with the greatest perceived advantages were selected [325, 326]. Factors such as awareness of energy consumption and the perception of households of electricity/gas consumption can influence energy efficiency decisions in this way. The combined outcomes of personal and contextual factors create the behaviour [428]. The main categories of personal, contextual, and motivational factors are presented in Figure 3.2.

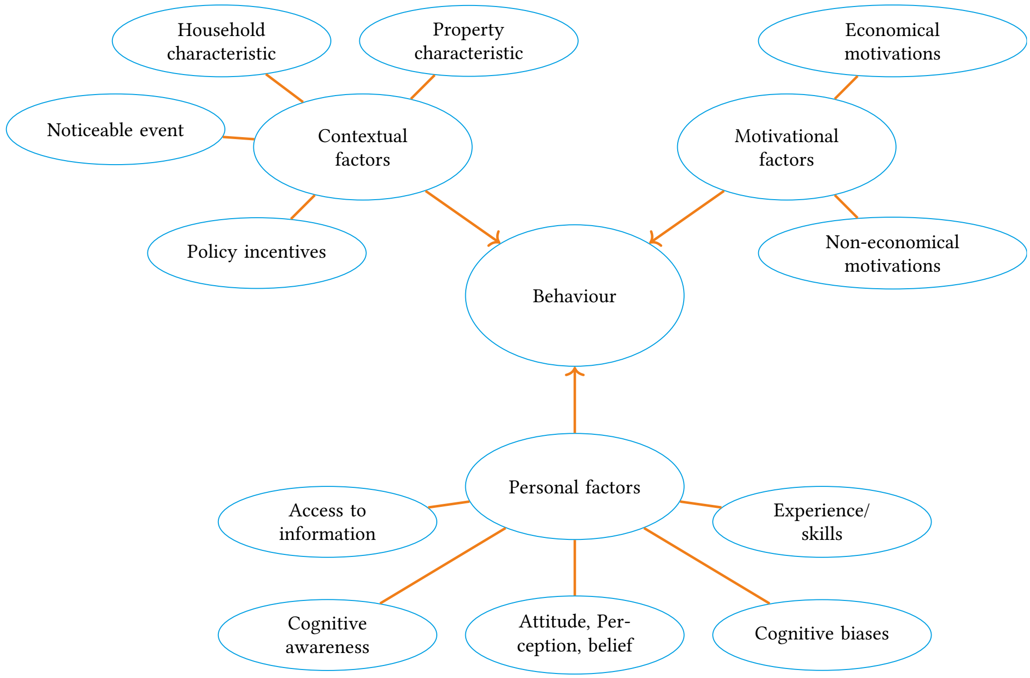


FIG. 3.2 behaviour-influencing factors on homeowner energy efficiency renovation decision-making process

Steemers and Yun [417] investigated the direct and indirect effects of different factors on household energy consumption for the residential sector of the United States. The main conclusions were: (1) physical characteristics, e.g. climate and heating system type, are important factors for heating; (2) income has an indirect effect on energy usage for space heating and cooling; (3) the number of heated/ cooled rooms, and the frequency of air-conditioning use are the main variables that influence energy consumption for space heating and cooling. Brounen, Kok, and Quigley [62] examined the impact of *household and socio-demographic characteristics, awareness, and literacy*. The authors measured the energy awareness by defining the question of "How much do you pay for their monthly gas/ electricity consumption?" Their conclusions included: (1) age is identified as the main demographic factor that influences energy consumption. Older households with higher income choose higher comfort levels by changing the thermostat settings; (2) No significant relation is identified between consumer behaviour and energy literacy/ awareness. The current study used a similar question to measure energy awareness. In a study focused on the Chinese residential sector, the probability of retrofitting of dwellings was higher for households who were older [486]. In another study. Schley and DeKay [397] investigated the cognitive accessibility of 730 households in four similar case studies in the United States. All four studies provided evidence of cognitive accessibility for people's inaccurate estimates of energy consumption. Regarding EERs, few studies have been conducted on evaluating the impacts of contextual and personal factors. The impact on energy efficiency measures of building and household characteristics, and satisfaction with the existing building envelope were investigated by Nair, et al. [326].

Huebner et al. [206] examined the impact of different factors, including building characteristics, socio-demographics, attitudes and, self-reported behaviours on energy consumption in the residential sector in the United Kingdom. They concluded that building characteristics explained the major share of variance in energy consumption. Socio-demographics and attitudes had a lower impact on energy consumption. Vassileva, et al. [460] concluded that household characteristics, type and usage of electrical appliances, and attitudes towards electricity consumption had significant impacts on electricity consumption. In another study by G. Huebner et al. [205], appliance types and sizes, and household size were the most significant variables in electricity consumption. The impact of building and household characteristics was evaluated for the residential sector in the Netherlands and Denmark [454]. Household and building characteristics each explained approximately 50% of the variance in heating consumption. In the category of property characteristics, the benefits of using different EERs (e.g. insulation, double glazing, PV panels) and the challenges in implementing these technologies were also identified as important factors. For example, double glazing, insulation, and smart heating systems can improve the indoor climate and building comfort [218]. Risholt and Berker [376] studied the owner-occupied sector in Norway. They found a higher probability of EER among energy-conscious households and/or ones with relevant professions and knowledge. In Germany, collaboration and the transfer of knowledge by households were found to be an effective approach for motivating them in conducting EERs [424]. Pothitou, et al. [361] found significant and positive relations between environmental values and knowledge on energy-saving behaviours, attitudes, and habits in a survey of 249 households in England.

Regarding policy incentives in the category of contextual factors, marketing campaigns and subsidies were found to be influential for Nordic countries. Also, the trustworthiness of one-stop-shops was identified as the main limitation in some cases [275, 276]. The impact of feedback, i.e. display (an energy monitoring device), on energy consumption was studied for the Swedish private rental sector by Nilsson et al. [337]. They found no significant impact of displays on energy consumption, the reasons being for this being the difficulty in understanding how to work with displays and the resistance to changing behaviour. The motives in using displays were also identified, such as curiosity and interest, cost-savings, and environmental concerns.

Understanding cognitive biases involved in home renovation decisions and designing interventions to overcome them (i.e. de-biasing tools) can help increase the home renovation rate. De Vries, et al. [88] introduced perceived hassle factors as an important barrier in conducting EERs. People generally postpone taking these energy efficiency measures to avoid the stress anticipated due to the accumulation of hassles during the awareness, consideration, and decision stages. Wilson, et al. [478] investigated the importance of attitudes and social norms to renovation and EERs. These influencing factors were identified as significant for different stages of thinking about renovating; planning renovations; and finalising renovations. Klockner and Nayum [242] examined the determinants of EERs for private owners in Norway by exploring the relationship between attitudes and energy efficiency investment decisions. The authors determined the importance of feelings of moral obligation to act, attitudes, and self-efficacy as determinants of the intention to consider EERs. It is important to understand the households' perceptions in energy consumption relative to other households. This can indicate whether they take action to improve the energy performance of their dwelling [42, 256]. Our study includes these types of factors in the regression analyses to evaluate the effects on renovation decisions.

Motivational factors shape the intention to behave, and finally, the actual behaviour [12, 188, 189]. Households' motivations need to be identified to upscale EERs in the owner-occupied sector [325, 342, 480]. Cost-savings on energy bills, increased comfort, and carbon footprints are examples of the identified motivational factors for EERs. Various categorisations of motivational factors are provided in the literature: economic, social, and environmental motivations were studied by Organ, et al. [342]; commonly identified motivations (e.g. thermal comfort) and occasionally identified motivations (e.g. property value) were examined by Wilson, et al., [480]; economical motivations (e.g. paybacks) and non-economical motivations (e.g. increasing thermal comfort) were studied by Friege and Chappin [149]. In a European research project, the motivational factors related to EERs in the building sector were investigated for Cyprus, Denmark, and Sweden. In terms of economic motivation, Danish households were motivated mainly by paybacks, whereas Swedish and Cypriots households were motivated by cost-savings. Baumhof et al. [39] examined the factors that influenced German owner-occupiers of single and multifamily houses. In a case study from Tanzania, the initial decisions for adopting solar PV energy were influenced by the motivational factors of technology, cost, warranty, and service for low-income and young households [409]. Additional motivational factors were the appearance of houses, lower dependency on fossil fuels, and the improved usability of existing space.

In addition to the motivational factors, personal factors such as the attitudes, values, and beliefs of households were identified as influencing household motivations, e.g. as environmentally friendly or not. Social norms and social influence could be considered as both internal, i.e. the household perception of social norms, and external factors, i.e. acceptability by society, influence on household motivations. Haque, et al., [187] investigated the role of socio-cultural attitudes and practices in the acceptance of energy technologies by low-income households in Mumbai and Cape Town. For instance, households' attitude for accepting solar energy was to make apparent their energy lifestyles to their communities. In a case study of Canada, the household characteristics and motivational factors of renovators were investigated. The energy cost savings, financial incentives, and costs of EERs were identified as significant factors using econometric analysis and given several building and household characteristics [154]. Table 3.2 presents the main influencing factors that will be evaluated in this study.

TABLE 3.2 Personal, contextual, and motivational factors that are going to be tested in this study

Contextual factors	Personal factors	Motivational factors
- Building types	- Information and awareness	- Cost-saving on energy bill
- Construction periods		- Increasing comfort
- Energy labels	- Attitudes and beliefs	- Due to maintenance
- Age groups	- Experience, skills	- For the environment
- Income	- Perception of households	- Improving ventilation
- Education	regarding energy consumption	- Reducing noise
- Household composition	compared to others,	- Increasing the house value
- Number of people	- Awareness of	- Making the property
- Agent performing the EERs	energy consumption	more saleable
- Types of maintenance associated with EERs		Motivations extracted from
- Noticeable event, e.g., moving home		
Contextual factors extracted from:	**Personal factors extracted from:**	**Motivations extracted from:**
[62, 113, 206, 326, 417, 454, 460, 480]	[62, 218, 376, 478, 480, 42, 88, 163, 206, 242, 256, 326, 361, 460]	[39, 149, 154, 187, 325, 342, 409, 480]

3.3 Methodology

3.3.1 The Netherlands housing survey energy module 2018

In this study, the Netherlands housing survey energy module 2018[7], which is the most recent one, is used. This database comprises 4506 dwellings of which 63% (2,878) belong to the owner-occupied sector. Data about the personal and motivational factors are mainly from the survey in 2018. The housing and building characteristics were collected from sources other than the survey. In addition to this, the main purpose of the national survey was to provide a representative sample of Dutch society. From this dataset, the following data are used: (1) renovators and potential renovators per type of EER, i.e. double glazing, insulation, solar PV panel, and, sustainable heating; (2) contextual factors, such as household and building characteristics (part of the extracted data, not the survey); (3) personal factors, such as the perceptions of the household of their own behaviours are assessed in different ways, for instance, whether they deliberately changed their behaviour, or how they perceive themselves compared with other households in terms of energy consumption; and (4) motivations for EERs. In the following, the descriptive analyses of the main variables in the logistic regression analyses are presented.

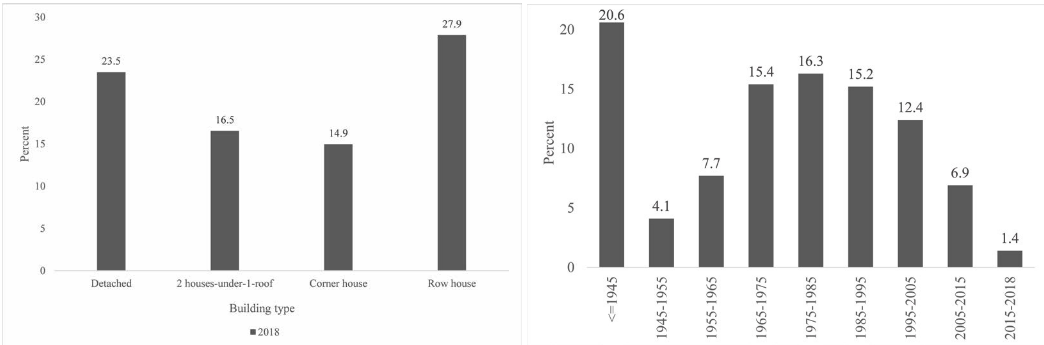
3.3.2 Building characteristics and household profiles

The percentages of single and multifamily households are around 83% and 17%, respectively. In addition, row houses have the highest percentages, and detached houses have slightly lower percentages than row houses. In 2018, 28% and 23% of houses were row houses and detached houses, respectively. In terms of the age of the buildings, the category for the oldest buildings (including buildings constructed before 1945) contained

7 The Dutch Ministry of the Interior and Kingdom Relations conducts a survey every 5–6 years on the energy consumption, energy behaviour of households, as well as the investment behaviour of households with regard to energy-saving measures in the rental and private building stocks. The Netherlands housing survey energy modules also contains other variables that are collected through the dwelling inspections, reports on energy consumption, other datasets, such as the Netherlands Enterprise Agency (in Dutch: Rijksdienst Voor Ondernemend Nederland (RVO)) dataset, containing building characteristics, such as energy labels [483].

the highest number of houses (around 22%) in the dataset. Other age categories contained buildings which were built within a period of 10 years (Figures. 3.3a and 3.3b).

The energy labels[8] of 2018 are presented in Figure 3.4. (1) Labels B and C accounted for the largest percentages of buildings with energy labels; (2) The proportion of buildings having energy labels (G, F, E, and D) was lower than the proportion of houses having energy labels (C, B, A, and A+).



(a) Building types (b) Period of Construction (years)

FIG. 3.3 building characteristics of the Netherlands housing survey energy module 2018. 17% of values are missing for the building types

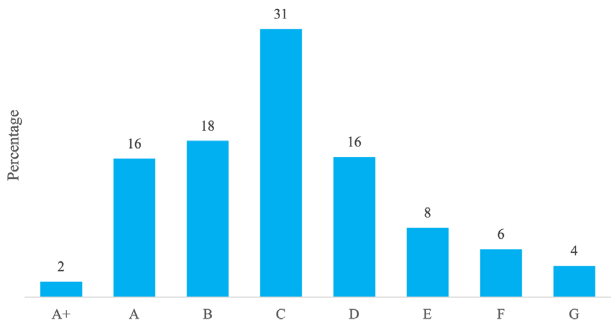


FIG. 3.4 Distribution of buildings with different energy labels in the Netherlands housing survey energy module dataset of 2018

8 An obligatory energy labelling of existing dwellings is dictated for European countries by Energy Performance of Building Directive (EPBD). In the Netherlands, the energy labelling system is implemented since 2008. The energy label is calculated using the building characteristics, heating, ventilation, and cooling systems, and standard usage characteristics [277].

A lower percentage of renovators performed the work by themselves in 2018, namely, 16% compared with 22% in 2012. Table 3.3 presents the household profiles, for example, more than 50% of homeowners were 54 years old or older, and more than 50% of households had higher education.

TABLE 3.3 Household profile (The Netherlands housing survey energy module 2018)

Variable	Categories	Frequency	Percent
Age (years old)	17-24	18	0.6
	25-34	256	8.9
	35-44	350	12.2
	45-54	444	15.4
	55-64	753	26.2
	65-74	785	27.3
	75 and older	258	9
Number of people in the house	1	643	22.3
	2	1428	49.6
	3	293	10.2
	4	372	12.9
	5	108	3.8
	6	26	0.9
	7	6	0.2
	9	1	0
	11	1	0
Income	< 36k	312	10.8
	36k-54k	632	22.0
	54k-72k	694	24.1
	72k-108k	760	26.4
	> 108 k	466	16.2
Education	Low	525	18.2
	Middle	774	26.9
	High	1536	53.4

Table 3.4 presents the personal factors that were provided in the energy module 2018. For example, the majority of households, approximately 59% and 79%, indicated that they deliberately reduced their gas and electricity consumption, respectively. Furthermore, most respondents (45%) indicated that they were well aware of their energy consumption. 38% of respondents perceived that they were consuming less energy compared with other households.

TABLE 3.4 Personal factors (The Netherlands housing survey energy module 2018)

Factor	Categories	Frequencies	Percent
- Deliberately reducing gas			
Have you consciously reduced gas consumption for instance by turning down heating in the past 12 months?	Yes	1694	58.86
	No	1094	38.01
- Deliberately reducing electricity			
Have you consciously reduced electricity consumption for instance by turning off the lights in the past 12 months?	Yes	2271	78.91
	No	589	20.47
- Deliberately using energy efficient devices			
Have you consciously replaced appliances that used a lot of energy with energy-efficient appliances in the past 12 months?	Yes	834	28.98
	No	1959	68.07
- Awareness on energy consumption			
Are you aware how much gas/electricity your household uses per year?	Well-aware	1289	44.79
	Aware	928	32.24
	Not-aware	647	22.48
- Household perception on energy consumption compared to the other households			
Do you perceive that your household uses more/less gas/electricity than other households?	Much more	47	1.63
	More	438	15.22
	Similar	991	34.43
	Less	172	5.98
	Much less	172	5.98

In the energy module 2018, questions were asked regarding the motivations towards EER for renovators and potential renovators (with yes/no answers). “Due to maintenance, to save energy costs, and to improve comfort” showed the highest percentages among the motivation factors (Table 3.5).

TABLE 3.5 Motivation factors (The Netherlands housing survey energy module 2018)

Drivers	Due to Mainte-nance	To reduce noise	To reduce moisture problem	To improve comfort	To save energy costst	For the en-viron-ment	To resale better	To increase the house value	A home-owner association has requested
Renovators	1138 (39.5)	187 (6.5)	256 (8.9)	961 (33.4)	1148 (39.9)	942 (32.7)	402 (14.0)	559 (19.4)	74 (2.8)
Potential renovators	453 (15.7)	62 (2.2)	159 (5.5)	561 (19.5)	796 (27.7)	742 (25.8)	297 (10.3)	401 (13.9)	69 (2.4)

3.3.3 Method of Analysis

The impacts of behaviour-influencing factors were investigated for different energy efficiency measures. The dependent variable was whether households had implemented/planned to conduct the specific energy-saving measures in the last five years/next two years. The independent variables were contextual, personal, and motivational factors (Table 3.6). The dependent variables were binary (whether they had installed or will install the energy efficiency measures), therefore, logistic regressions were conducted. This study focused on four types of EERs: double glazing, insulation, solar PV panels, and sustainable heating. These energy-saving measures were investigated for both renovators and potential renovators, and in total, eight regressions were estimated. Table 3.6 shows a list of independent variables having different scales.

TABLE 3.6 Explanatory variables with different scales

Contextual factors	Scale	Contextual factor	Scale	Personal factors	Scale
Building types	4/5 categories	Agent perform-ing the EERs	Binary	Awareness of energy consumption	Three-point Likert scales
Construction Periods	8 categories	Type of Maintenance	Binary	Deliberately reduce gas and electricity consumption	Binary
Energy labels	7 categories	Relocation	Binary	Perception of house-holds on energy con-sumption compared to other households	Three-point Likert scales
Age groups	6 categories	Household composition	3/5 categories	Deliberately replace non-efficient devices with efficient ones	
Income	3/5 categories	Cost	4 categories	Motivational factors	Scale
Education	3 categories	Household Composition + age	8 categories	All motivations	Binary

In the computation, a backward elimination method was used. In this method, a complex model including all the potential variables is developed using a theoretical framework. At each step, the non-significant variables are removed from the regression. The elimination is based on the likelihood ratios, i.e. removal testing is done based on the likelihood-ratio statistic using the maximum partial likelihood estimates. A typical logistic regression output contains the following outputs in addition to the beta coefficients of independent variables (β), and degrees of freedom (df) in Statistical Package for the Social Sciences (SPSS). (1) The odds ratios (column exp(B)), describes the degree of association between the dependent and independent variables, and this measure is used to compare the relative probabilities of the occurrence (chance criterion) of the renovation. For the categorical variables, generally, the chance criterion is compared with the reference category. Binary variables are considered categorical variables with only two categories. The probability of respondents selecting category *j* can be calculated using the chance criterion $(exp\,(\beta_j)/(\sum_{i=1}^{n} exp\,(\beta_j) \times 100)$ (2) A Wald test demonstrates the significance of each coefficient in the regression. The null hypothesis is that the coefficient of the independent variable is equal to zero. The hypothesis is rejected when the p-value (specified in the column called "Sig.") is lower than the critical p-value of 0.05 (or 0.01, 0.1, etc.). (3) S.E. is the standard error around the coefficient for each variable.

There are some assumptions made in conducting logistic regressions: (a) dependent variable is the log of the binary variables; (b) The independent variables should not indicate multicollinearity; (c) the data should contain a large sample size. The validity of the multicollinearity assumption is verified by calculating the Variance Inflation Factors (VIF). A VIF = 2.5 is the initial point of concern, and a VIF >10 shows multicollinearity [298]. The VIFs for eight regressions are presented in Table 3.7. There is no serious multicollinearity between the independent variables in the sample.

TABLE 3.7 Multicollinearity tests in regressions

	Max VIF	
Group	Renovators	Potential renovators
Double glazing	1.139	1.035
Insulation	1.142	1.035
PV panel	1.353	1.82
Sustainable heating	1.224	1.124

Binary logistic regression model is used to describe the relation between the dependent and independent variables:

$$Log\left(\frac{P_{\mathrm{EER}}}{(1-P_{\mathrm{EER}})}\right) = \beta_0 + \beta_1 X_{\text{Contextual factors}} + \beta_2 X_{\text{Personal factors}} + \beta_3 X_{\text{Motivational factors for EER}} \quad (3.1)$$

Where P is the probability of events, and X represents independent variables. After estimation, the omnibus tests of the model coefficients and the Hosmer and Lemeshow test were applied to validate the models (Table 3.8). The omnibus test checks whether the model estimates the outcome with the explanatory variables better than without [55]. The omnibus tests were statistically significant, and the models were better with explanatory variables than without. The Hosmer and Lemeshow test illustrated the goodness of fit, which is an insignificant factor for a good model.

TABLE 3.8 Assessing the regressions regarding the goodness of fit

Group	Type of energy Efficiency renovation	Omnibus Tests of Model Coeffi-cient			Hosmer and Lemeshow Test		
Renovators	Double glazing	230.406	22	0.000	4.363	8	0.823
	Insulation	222.116	15	0.000	8.068	8	0.427
	PV panel	386.857	31	0.000	2.280	8	0.971
	Sustainable heating	282.569	30	0.000	8.276	8	0.407
	Double glazing	163.918	25	0.000	11.390	8	0.181
Potential renovators	Insulation	246.713	17	0.000	11.501	8	0.175
	PV panel	265.910	20	0.000	4.708	8	0.788
	Sustainable heating	211.679	17	0.000	2.338	8	0.969

Table 3.9 presents the pseudo R-squared values and the likelihood ratio tests. The pseudo R-squared values are comparable to the R-squared values in terms of scale, i.e. ranging from 0 to 1, and interpretation (i.e. higher values indicate better model fit.). The likelihood ratio test examines whether the differences between two models (for the backward elimination method) are statistically significant [264]. A p-value < 0.05 indicates that the final model fits significantly better than the last estimated model.

TABLE 3.9 Pseudo R-Squared and Likelihood ratio test regarding the goodness of fit

Group	Type of energy efficiency	Pseudo.R.square McFadden	Cox and Snell (ML)	Nagelkerke (Cragg and Uhler)	Likelihood.ratio.test Df.diff.	LogLik.diff	Chisq	P value
Renovators	Double glazing	0.730530	0.927969	0.954009	-22	-1057.5	2115	0***
	Insulation	0.335050	0.323289	0.469731	-15	-332.32	664.65	6.309e-132***
	PV panel	0.794221	0.902731	0.953437	-31	-889	1778	0***
	Sustainable heating	0.822983	0.93187	0.968912	-27	-1008.7	2017.5	0***
Potential renovators	Double glazing	0.232710	0.183618	0.315606	-26	-102.5	204.09	1.4497e-29
	Insulation	0.241438	0.249350	0.358697	-17	-148.57	297.14	4.3777e53***
	PV panel	0.338751	0.373850	0.499177	-20	-222.38	444.76	1.0098e-81***
	Sustainable heating	0.330854	0.266027	0.438023	-21	-154.33	308.66	5.4673e-53***

For the visualisation of the results, the R programming language and the visreg package were used because the R package contained more options [58]. Using this package, the surface plots were depicted for two independent variables of the logistic regressions, and the probability of investment in specific types of energy efficiency measures [261].

3.4 Results

3.4.1 Renovators

Double glazing

Table 3.10 shows the logistic regression for influencing factors on the implementation of double glazing, insulation, PV panels, and sustainable heating by households[9]. Two categories of contextual factors significantly influence the installation of double glazing: building and household characteristics. The identified influencing building characteristics are year of construction and types of non-energy-efficient renovations. Houses that were constructed in the 1980s have the highest probability of installing double glazing. The relative probabilities of installing double glazing together with different non-EERs are investigated. These could be used to focus on the promotion of double glazing with the appropriate non-EERs. Overall, 70% of respondents mentioned that they conducted double glazing with "repaired/replaced the window frames". The main identified household characteristics are income and household compositions. With respect to household characteristics, households with children are twice as likely to install double glazing compared with one-person households. The probability of installing double glazing is higher in lower income groups and families with children when compared with other categories of incomes and household compositions (Fig 3.5). No personal factor is significantly identified regarding the decision to install double glazing. Households mainly install the double glazing to improve comfort, to reduce noise, to sell the house at a higher price, and to maintain the house. These reasons were described as primary motivations by 74%, 67%, 61%, and 60% of households.

9 Table 3.10 shows the main outputs of the logistic regressions. Appendix B presents all the outputs including β, df, S.E., Wald test, Exp(b).

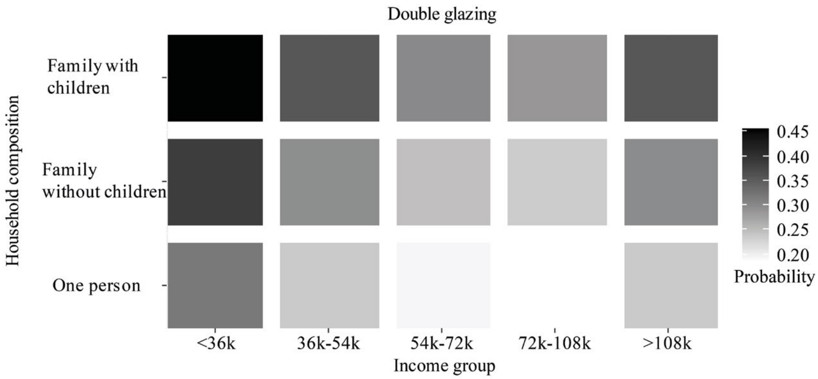
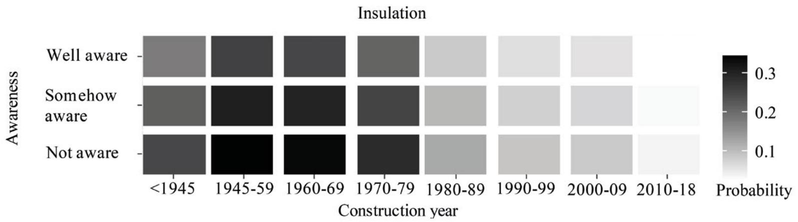


FIG. 3.5 The impacts of household composition and income on the installation of double glazing

Insulation of floors, roofs and walls

Among contextual factors, the building characteristic, more specifically the construction year, is identified as significant. The houses built between 1945 and 1959 and those built between 1960 and 1969 are significantly identified, and they have a higher probability of insulation installation compared with houses built before 1945. Among the personal factors, the main identified one is "deliberately changing behaviour to use less electricity". Households that changed their electricity consumption are more likely to insulate their houses. About 62% of these households insulated their houses. Another significant personal factor is awareness of energy consumption. The specified question is whether the households know how much gas/electricity they use per year. In this case, the data shows a reverse relationship between the installation of insulation and the claimed awareness of the households with respect to energy consumption. Contrary to what one would expect, the well-aware group has the lowest probability of installing insulation, and the not-fully-aware group has the highest probability. The more reasonable outcome would have been a direct relationship between awareness and performing insulation (Fig 3.6a). Human bias may play a major role here and requires more in-depth investigation. The last category of behaviour-influencing factors is motivational factors. The main identified motivations are "to improve comfort" and "to improve ventilation/moisture problem". The percentages of households that specified these motivations and insulated their houses are 77.4% and 60%, respectively. Figure 3.6b shows the highest probability of decision to insulate due to comfort and for buildings constructed before the 1980s.



(a) construction year and level of awareness of energy consumption

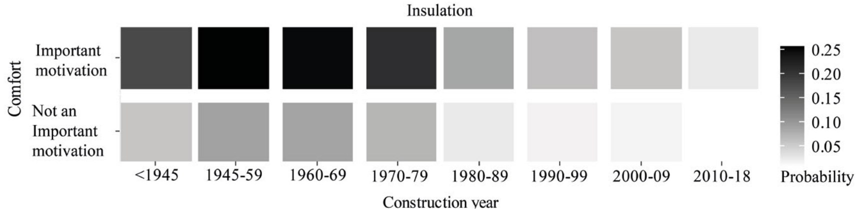


FIG. 3.6 The impacts of influencing factors on the decision regarding insulation (renovators)

Solar PV panels

The identified contextual factors belong to the energy labels, household characteristics, agent performing the EERs, and types of maintenance associated with EERs. The implementation of this energy efficiency measure depends strongly on the energy labels. A clear trend can be seen between the installation of PV panels and the energy label of the houses. The houses with higher energy labels are more likely to install PV panels compared to the ones with the worse energy labels. As an example, the households with energy label “A” are 5.6 times more likely to install the PV panels compared to those with energy label “B”. The detached houses are more likely to install PV panels compared to 2-under-1-roof and maisonette dwellings. The chances are 2.4 and 10 times, respectively. As expected, 70% of households asked an expert to install the PV panels instead of installing the panels themselves. The installation of PV panels can take place whenever the households replaced/repaired the roof or replaced/repaired the windows frames. Among household characteristics, the coefficients of age and household composition are statistically significant. A clear trend can be identified between the installation of PV panels and the Head of Household (HOH) age. Older HOHs are more likely to install PV panels. For instance, HOHs between the ages of 55 and 64 are almost 5 times more likely to install PV panels compared with those between the ages of 17 and 35 years of age. Similar to double glazing, households with children are more likely to install PV panels compared with one-person households or households without children. The chances are 6.2 and 2.2 times, respectively. Furthermore, a dwelling with the energy label

“A” has a higher chance of solar PV panel installation. Figure 3.7a demonstrates the probability of installing solar panels per household composition and the HOH age group. There is a greater number of significant personal factors when comparing solar PV panel installation with double glazing and insulation. The first group of personal factors is behavioural changes by households: (1) deliberately replacing the non-energy efficiency devices with efficient ones, and (2) deliberately reducing gas consumption. Overall, the 34% and 38% of households that adopted these behavioural changes installed PV panels for their houses. Second, the household perception of electricity consumption compared to the others is significantly identified, as well. The households that perceived themselves as using more energy than others were 2.6 times more likely to install PV panels compared with households with a perception of similar energy consumption. The last category of behaviour-influencing factors is motivational factors. The most significant motivations are “saving energy costs” and “for the environment”. Of those who installed PV panels, 87% and 74% of respondents mentioned these as primary motivations. The other significant motivations are “due to maintenance” and “to improve comfort”, mentioned by 26% and 15% of respondents. Figure 3.7b shows the importance of cost saving on energy bills for different groups of households.

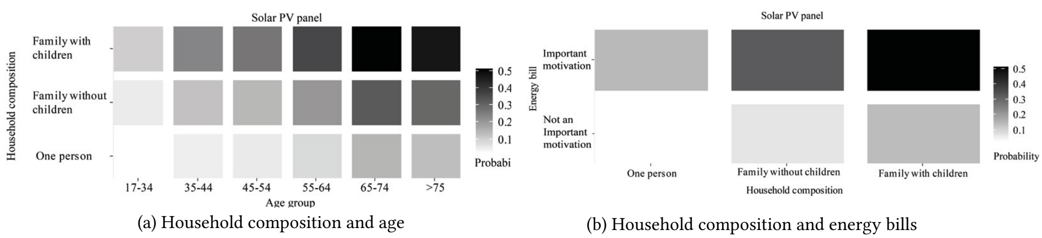


FIG. 3.7 The impacts on the decision regarding installation of PV panel (renovators)

Sustainable heating

Significantly identified contextual factors among building characteristics include the construction year, energy label, and building type. The construction year plays an important role in houses constructed between 1990 and 1999 and 2000 and 2009. Regarding boiler replacement, houses constructed between 1990 and 1999 are 4 times more likely to replace the boiler, and houses constructed between 2000 and 2009 are 4.4 times more likely to replace the boiler than all houses constructed in years outside of these years. The second significant building characteristic is the energy label. In contrast to the PV panel, the houses with lower energy labels have a higher probability of installing or replacing the boilers. The highest significant energy label is for energy label “F”, followed by energy labels “G”, “E”, and “D”. The building type is also a significant variable. Among different types of houses, all building types have a significant probability of installing boilers, though with a lower probability than apartments and semi-detached houses. Among the personal factors, deliberately changing gas consumption behaviour is a significant variable. Of the households that changed their behaviour, 69% have installed or replaced sustainable heating. The second significant personal factor is the household’s perception of their energy consumption compared to the other households. The households that perceive higher energy consumption as compared with other households are 2.1 times more likely to replace their boiler compared the ones who perceive lower energy usage. The main identified and highly significant motivating factor is “due to maintenance”. Of households that stated this motivation as an important one, 91% have conducted EERs.

TABLE 3.10 Summary of logistic regression analyses for renovators

Energy Efficiency Renovations	Double glazing			Insulation			Solar PV panel			Sustainable heating system		
Coefficients	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.
Construction year												
<1945			0.00***			0.00***						0.02**
1945-59	1.19	0.35	0.63	1.58	0.25	0.07				0.92	0.54	0.88
1960-69	1.48	0.30	0.19	1.53	0.23	0.06				0.56	0.49	0.24
1970-79	1.11	0.25	0.69	1.22	0.19	0.28				0.82	0.44	0.65
1980-89	1.83	0.28	0.03	0.44	0.26	0.00**			1	1.14	0.50	0.79
1990-99	0.20	0.44	0.00***	0.31	0.32	0.00***				4.01	0.52	0.01**
2000-09	0.07	1.03	0.01*	0.29	0.42	0.00**				4.38	0.69	0.03*
2010-18	1.29	0.79	0.74	0.13	1.04	0.05				2.77	2.10	0.63
Energy labels												
A and A+									0.00***			0.10
B							0.17	0.38	0.00***	3.58	0.49	0.01**
C							0.17	0.33	0.00***	3.83	0.52	0.01**
D							0.13	0.42	0.00***	5.58	0.61	0.00**
E							0.08	0.60	0.00***	7.13	0.70	0.00*
F							0.07	0.90	0.00**	7.74	0.83	0.01
G							0.11	-1.10	0.04*	7.62	1.08	0.06

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TABLE 3.10 Summary of logistic regression analyses for renovators

Energy Efficiency Renovations	Double glazing			Insulation			Solar PV panel			Sustainable heating system		
Coefficients	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.
Building type												
Detached									0.01			0.00**
2 under 1 roof							0.42	0.36	0.02*	4.34	0.45	0.00**
Corner							0.85	0.39	0.68	3.33	0.40	0.00**
Intermediate							0.78	0.32	0.43	3.33	0.40	0.00**
Maisonette							0.10	0.78	0.00**	4.16	0.47	0.01**
Done by an expert							2.26	0.32	0.01*			
Age category												
17-35									0.05			
34-44							2.70	0.77	0.20			
45-54							3.16	0.74	0.12			
55-64							4.94	0.76	0.04*			
65-74							9.12	0.78	0.00**			
>75							7.97	0.90	0.02*			
Household composition												
One-person			0.14						0.01*			
Family without children	1.35	0.27	0.27				2.84	0.44	0.02*			
Family with children	1.78	0.30	0.05				6.16	0.57	0.00*			
Income												
<36k			0.28									
36k-54k	0.67	0.39	0.29									
54k-72k	0.51	0.37	0.07									
72k-108k	0.49	0.38	0.06									
>108k	0.67	0.40	0.31									
Cost												
500-6500			0.00						0.03*			0.01*
6500-12500	2.52	0.25	0.00***				0.61	0.36	0.17	0.17	0.59	0.00**
12500-18500	1.69	0.39	0.18				0.56	0.57	0.31	0.19	1.09	0.13
>18500	7.67	0.45	0.00***				0.11	0.79	0.005**	0.00	5512	1.00
Replace/repair roof							0.43	0.38	0.03*			
Replace/repair window frames				0.54	0.19	0.00**	0.46	0.34	0.02*			
Deliberately reducing gas consumption							0.61	0.27	0.06	2.25	0.27	0.00**
Deliberately reducing Electricity usage				1.68	0.20	0.01*						
Deliberately replacing non-efficient devices with efficient ones							0.51	0.26	0.01*			

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TABLE 3.10 Summary of logistic regression analyses for renovators

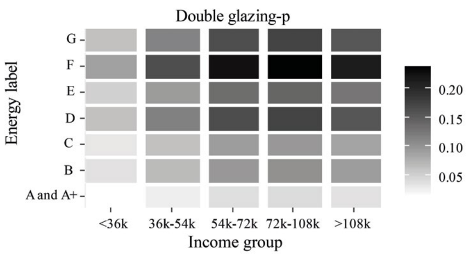
Energy Efficiency Renovations	Double glazing			Insulation			Solar PV panel			Sustainable heating system		
Coefficients	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.	Exp(B)	S.E.	Sig.
Awareness of Energy consumption												
Well aware						0.06						
Partly aware				0.84	0.19	0.34						
Not aware				0.66	0.18	0.02**						
Perception of households on energy use compare to others												
More and much more									0.01*			0.01*
Similar							0.38	0.40	0.01*	1.08	0.34	0.81
Less and much less							0.92	0.34	0.81	0.46	0.34	0.02*
To improve comfort	2.86	0.20	0.00**	3.43	0.17	0.00***	0.17	0.26	0.00***	0.38	0.27	0.00***
Due to maintenance	1.54	0.19	0.02*	0.49	0.14	0.00***	0.36	0.25	0.00***	11.40	0.37	0.00***
To reduce noise	2.12	0.26	0.00***									
To improve moisture problem				1.52	0.18	0.02*				0.13	0.60	0.00***
For the environment				0.73	0.14	0.03	2.95	0.31	0.00***	0.37	0.27	0.00***
To increase house value										0.55	0.31	0.05*
To save energy costs	0.73	0.20	0.13				6.48	0.37	0.00***			
To resale the house better	1.6	0.21	0.02*									
Constant	0.15	0.43	0.00***	0.16	0.29	0.00***	0.10	0.99	0.02*	0.09	0.78	0.00***

*Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

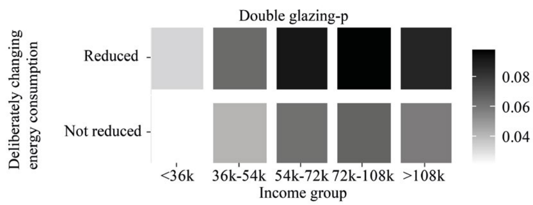
3.4.2 Potential renovators

Double glazing

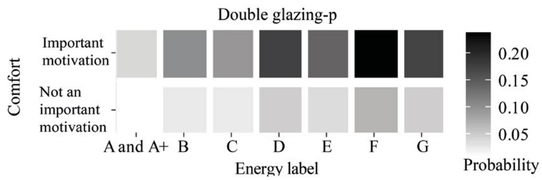
Among the contextual factors, two categories of building and household characteristics are identified significantly (Table 3.11). First, the energy labels significantly influence the decision to double-glaze for potential renovators. The highly significant energy label is "F". The households living in this category of dwellings will be 7.2 times more likely to plan for double glazing installation compared with energy labels A and A+. After "F", the energy labels "G" and "D" have the highest probability of installing double glazing in the future. Second, the households that earn more than twice the most frequent income in the sample are more likely to plan for double glazing. Among eight household composition types, the one-person households with a head of household older than 64 are 3.6 times more likely to double-glaze compared with reference category[10]. Figure 3.8a indicates that the higher-income groups and the buildings with lower energy labels are planning for double glazing to be completed as well. Personal factors such as deliberately using less gas and electricity as well as awareness of energy consumption are significantly identified. Of the households that have deliberately changed their behaviours by reducing gas consumption, 60% are planning to implement double glazing. Figure 3.8b indicates the evidence for these personal factors and all levels of income. In contrast, only 35% of households with deliberate changes in electricity consumption are planning to conduct double glazing. The households less aware of energy consumption are planning more for double glazing compared to those partly aware and well-aware households on energy consumption. The main motivating factors are “to improve comfort”, “to reduce noise”, “due to maintenance”, and “to improve ventilation or moisture problems”. Overall, 80%, 70%, 65%, and 59% of households that mentioned the importance of these motivations are planning to install double glazing in the next two years, respectively. A lower percentage of households (35%) is significantly identified as conducting double glazing to reduce environmental impact. Figure 3.8c shows the importance of comfort per energy label of dwellings.



(a) Different income groups and energy labels of dwellings



(b) The behavioural change of deliberately reducing energy consumption and different income groups



(c) The motivational factor of to improve comfort and different energy labels of dwellings

FIG. 3.8 Impacts of the influencing factors regarding the future decision on installing/replacing the double glazing (potential renovators)

10 The categories of household composition differ for the double glazing and solar PV panel. Therefore, this variable is not included in the table 3.11. Please see appendix B.

Roof, wall, and floor insulation

Among the contextual factors, the construction year, building type, and ages of the occupants are significantly identified. Construction year is a highly significant factor, especially for the buildings that are constructed between 1945 and 1959. Approximately 70% of the building owners are likely to insulate their houses in the next two years. In addition to this, there is a trend for owners of newer dwellings to be less likely to plan for insulation compared to owners of older dwellings [Exp(B) is decreasing: 2.6, 1.16, 0.51, 0.23, 0.03]. Owners of row houses are 1.9 times more likely to plan for insulating their houses compared to those in apartment houses. Figure 3.9a shows the impact of construction year and building type on the likelihood of insulation installation. No personal factor is significantly identified. Of those wanting to improve the comfort of the dwelling, 82% are more likely to plan to insulate their houses compared to the others. Figure 3.9b confirms the importance of comfort per construction period. The older the building, the more likely households were to mention this highly significant motivational factor. Of households that mentioned the importance of maintaining the house, 33% are likely to plan for insulation.

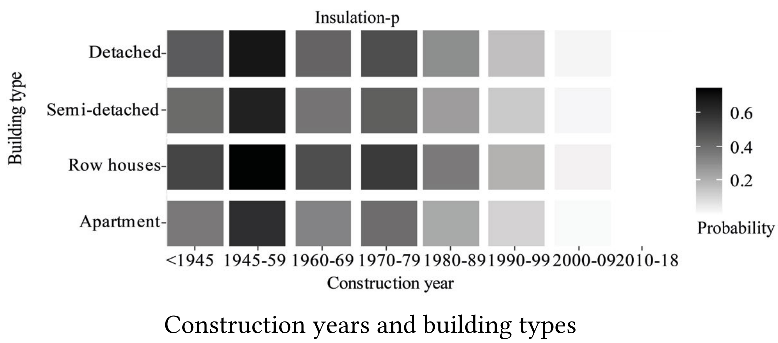


FIG. 3.9 Impacts of the influencing factors on the future decision regarding installing/replacing the insulation (potential renovators)

Solar PV panels

Among contextual factors, construction years, household compositions, and level of education significantly influence the planning for installation of PV panels. A clear trend can be observed for construction year. There is a higher probability of planning for PV panel installation for newer buildings. In this respect, buildings built between 2010 and 2018 are 5.14 times more likely to have PV panels than buildings built before 1945. Non-family households, which comprise a group of people, are 6.8 times more likely to install PV panels compared with one-person households. Among personal factors, 40% of households that mentioned deliberately reducing gas consumption plan to install PV panels in the future. Overall, the main identified motivational factors are saving energy costs, increasing the house value, and caring for the environment. Of the households that are planning to install PV panels, 76%, 65%, and 63% described these motivations as the important ones, respectively. Figure 3.10 shows the importance of energy bills per construction period and may indicate that households with newer buildings and the motivation of cost savings are more likely to install PV panels.

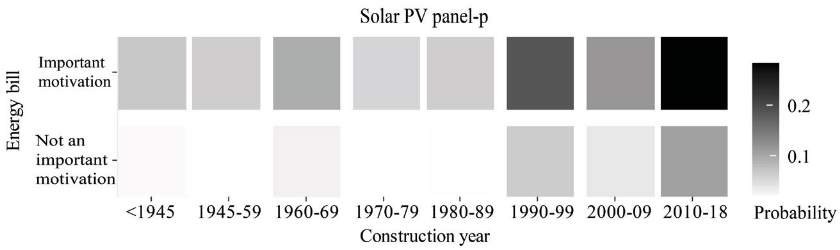


FIG. 3.10 The impacts of construction years and saving on energy bills regarding the future decision on installing/replacing the solar PV panels (potential renovators)

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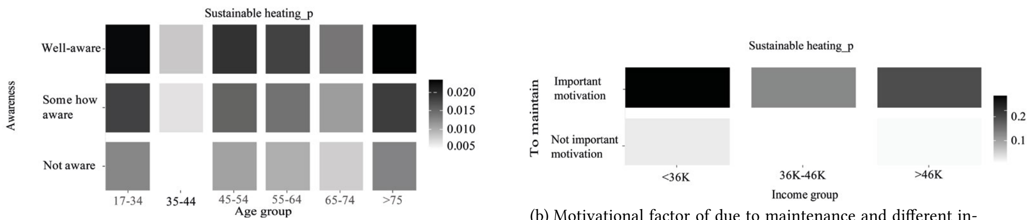
Sustainable heating

The main identified contextual factors are the construction period, age, and income. The majority of construction periods have highly significant coefficients. Similar to the year of construction for renovators, the probability of planning for boiler replacement is highest for the construction period of 2000–2009 due to a boiler's expected lifespan of 10–13 years. Younger and lower-income household groups are more likely to be planning to replace boilers than older and higher-income groups.

Among personal factors, the awareness of energy consumption is significantly identified. The well-aware households are 1.8 times more likely to be planning to replace a sustainable heating system compared to not-fully-aware households. Figure 3.11a shows the effects of age and awareness of energy consumption. Among motivating factors, the most significant one is "due to maintenance". Overall, 93% of households that mentioned this motivation are planning to install or replace a boiler in the next two years. The second important motivation is "for the environment". Of households mentioning this motivation, 58% are planning to install a more energy efficient boiler. Other significant motivational factors are "to improve comfort" and "to improve ventilation and moisture problem". Figure 3.11b indicates the importance of the motivational factor "due to maintenance" per income group of households. The lowest income groups mentioning installing or replacing a heating system for the reason of maintaining the dwellings are more likely to be planning this type of energy efficiency measure compared with the other two groups.



(a) Awareness of energy consumption and different age groups

(b) Motivational factor of due to maintenance and different income groups

FIG. 3.11 Impacts of the influencing factors regarding the future decision on installing/replacing the sutaiable heating systems (potential renovators)

TABLE 3.11 Summary of logistic regression analyses for potential renovators

EERs			Double glazing			Insulation			Solar PV panel			Sustainable heating system		
Coefficients			Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.
Contextual factors	Building characteristics	Construction year						0.00***			0.00***			0.00***
		<1945												
		1945–59				2.64	0.29	0.00***	0.92	0.37	0.82	0.51	0.60	0.26
		1960–69				0.88	0.27	0.64	1.42	0.34	0.30	1.40	0.43	0.43
		1970–79				1.16	0.22	0.50	0.82	0.28	0.46	2.58	0.33	0.00**
		1980–89				0.51	0.27	0.01*	0.91	0.30	0.75	2.72	0.36	0.01**
		1990–99				0.23	0.37	0.00***	3.03	0.28	0.00***	2.31	0.38	0.03*
		2000–09				0.03	1.03	0.00***	1.78	0.32	0.07 .	5.28	0.39	0.00***
		2010–18				0.00	6379	1.00	5.14	0.47	0.00***	1.54	0.84	0.60
		Energy labels												
		A and A+			0.00***									
		B	2.65	0.51	0.06 .									
		C	2.50	0.47	0.05**									
		D	4.90	0.48	0.00***									
		E	3.82	0.52	0.01**									
		F	7.21	0.53	0.00***									
		G	4.85	0.60	0.01**									
		Building type_ Apartment						0.04*						
		Row houses				1.92	0.27	0.02*						
		Semi-detached				1.20	0.31	0.56						
		Detached				1.46	0.30	0.20						
	Household characteristics	Age category						0.10 .						0.14
		17–35												
		35–44				0.56	0.31	0.06 .				0.35	0.45	0.02*
		45–54				0.66	0.31	0.18				0.85	0.39	0.67
		55–64				0.56	0.30	0.05 .				0.78	0.37	0.52
		65–74				0.87	0.29	0.64				0.61	0.39	0.19
		>75				0.39	0.46	0.04*				1.02	0.52	0.97
		Education _low									0.17			
		Middle							0.61	0.28	0.08 .			
		High							0.64	0.26	0.08 .			
		Income			0.13									0.10
		<36k												
		36–46k	1.97	0.48	0.16							0.37	0.49	0.04*
		54–72k	2.93	0.47	0.02*							0.61	0.30	0.10
		72–108k	3.13	0.48	0.02*									
		>108k	2.75	0.51	0.05*									

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TABLE 3.11 Summary of logistic regression analyses for potential renovators

EERs		Double glazing			Insulation			Solar PV panel			Sustainable heating system		
Coefficients		Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.	Exp(*B*)	S.E.	Sig.
Personal factors	Deliberately reducing gas usage	1.53	0.24	0.08 .				0.67	0.18	0.03*	0.67	0.18	0.03*
	Deliberately reducing electricity usage	0.54	0.28	0.03*									
	Awareness of energy consumption_			0.15									0.14
	Not aware												
	Partly aware	0.61	0.27	0.07 .							1.43	0.32	0.26
	Well aware	0.66	0.26	0.10 .							1.82	0.30	0.05 .
	Perception of households on energy usage compared to others_									0.19			
	More and much more												
	Similar							1.52	0.24	0.08 .			
	Less and much less							1.19	0.23	0.46			
Motivation factors	To improve comfort	4.02	0.25	0.00***	4.68	0.18	0.00***	0.14	0.19	0.00***	0.34	0.24	0.00***
	Due to maintenance	1.92	0.21	0.00**	0.50	0.17	0.00***				13.33	0.25	0.00***
	To reduce noise	3.83	0.33	0.00***									
	To improve moisture problem	1.47	0.24	0.11							0.48	0.35	0.04*
	For the environment	0.52	0.21	0.00**				1.70	0.21	0.01*	1.40	0.23	0.14
	To increase house value							1.82	0.18	0.00***			
	To save energy costs							3.21	0.23	0.00***			
	Follow other people										0.11	1.04	0.03*
	Constant	0.01	0.93	0.00***	0.22	0.35	0.00***	0.24	0.43	0.00***	0.04	0.55	0.00***

*Note: Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*

3.5 Discussion

3.5.1 Evidence on behaviour-influencing factors in practice

The influencing factors and the associated empirical results are illustrated using the Netherlands housing survey energy module 2018. Table 3.12 presents the main important contextual, personal, and motivational factors per type of energy efficiency renovation. In the current study, contextual factors such as household and building characteristics are investigated. For renovators, the installation of double glazing mostly depends on the building and household characteristics. For older dwellings with more occupants, e.g. families with children, the owners are more likely to install double glazing. Houses that were constructed prior to 1980 have the highest probability for double glazing installation. The use of double glazing increased extensively in the 1980s. Therefore, it is probable that houses built after this time period had double glazing installed at the time of construction, while houses built before that require this renovation. For houses that are built before 1945, owners are approximately 3.5 times more likely to install insulation than houses built between 2000 and 2009. The first regulation for the Energy Performance Coefficient (EPC) for buildings was introduced around the 1990s. Dwellings constructed in the years after the introduction of EPC were forced to comply with the regulations of installing insulation; therefore, these houses did not install insulation in recent years. Because there was no such regulation for houses built between 1945 and 1969, these houses installed more insulation in recent years.

Houses with higher energy labels, especially energy label “A”, have installed more solar PV panels. Older heads of households (HOHs) and families without children were more likely to install solar PV panels compared with other groups. Buildings constructed from 1990–1999 and 2000–2009 have the highest probability of installing a new boiler. A plausible explanation is that the average lifetime of a boiler is between 10 and 13 years. Therefore, houses constructed between 2000 and 2008 should have changed their boilers in the time period specified in the questionnaire, 2013–2018. Buildings with the lowest energy labels and building types of row middle houses are more likely to install or replace a boiler. For potential renovators, the households with a lower energy label, especially energy label “F”, are more likely to be planning to install double glazing. Households with higher incomes are also more likely to plan to install double glazing compared with other income groups. This result indicates the high investment costs of double glazing, which makes people with lower incomes less likely to invest in this type of EER. It is more probable that non-family households and those with new houses plan for solar PV panel installations compared with others.

TABLE 3.12 Contextual, personal, and motivational factors per type of EERs.

Type of EERs	Group	Renovators	Potential renovators
Double glazing	Contextual factor	(a) Building characteristics (construction year: <1980), type of other renovations: repaired/replaced window frames) (b) Household characteristics (income: lower-income), household composition: family with children)	(a) Building characteristics (energy label: F, G, D) (b) Household characteristics (high-income group, household composition: older household)
	Personal factor	_	Deliberately reduce gas and electricity
	Motivational factor	To improve comfort	To improve comfort
		To reduce noise	To reduce noise
		To resell house	Due to maintenance, etc.
Insulation	Contextual factor	(a) Building characteristics (construction year: 1945–1959, 1960–1969)	(a) Building characteristics (construction year: 1945–1959, building type: row houses)
	Personal factor	- Deliberately reduce energy consumption - Awareness of energy consumption	_
	Motivational factor	To improve comfort	To improve comfort Due to maintenance
Solar PV panel	Contextual factor	(a) Building characteristics (energy label: higher e.g. A, building type: detached houses), type of other renovations: replaced/repaired roof/windows frame) (b) Household characteristics (age: older, household composition: family with children)	(a) Building characteristics (construction year: newer) (b) Household characteristics (household composition: non-family, education: higher)
	Personal factor	- Deliberately replace non-energy-efficient devices with efficient ones and reduce energy consumption -Perception of electricity consumption compared to others: perceived higher	Deliberately reduce energy consumption
	Motivational factor	- Saving energy costs -For the environment, etc.	-Saving energy costs -To increase house value -For the environment, etc.
Sustainable heating	Contextual factor	(a) Building characteristics (construction year: 1990–1999, 2000–2009, energy labels: F, G, etc., building type: apartments and semi-detached houses) _	(a) Building characteristics (construction year: newer) (b) Household characteristics (lower-income group and younger groups)
	Personal factor	Deliberately reduce energy consumption	Awareness of energy consumption (well-aware)
	Motivational factor	Due to maintenance	Due to maintenance for the environment

In terms of personal factors, household awareness of energy consumption is significantly identified for the installation of insulation and sustainable heating. Homeowners who aim "to deliberately change their behaviours towards energy consumption" are more likely to insulate and replace the boilers compared with others. In the context of EERs, motivational factors influence the individuals' behaviours as mentioned by Organ, et al., [342]. Wilson, et al. [480]. Friege and Chappin [149], and Baumhof et al. [39]. In our study, both renovators and potential renovators mentioned "improving comfort and maintaining good physical and structural conditions of the houses" as the main motivations for all types of EERs except for PV panels. Installation of PV panels is also motivated by "saving costs on energy bills", "the environment" (also for sustainable heating), and "increasing the house value". Double glazing has an additional motivational factor of "reducing noises".

3.5.2 Policy recommendations

Promoting EERs should be tailor-made for different cultures and target groups of households (e.g. sociodemographic traits). Dutch municipalities can set clusters of dwellings using household and building characteristics. These two categories of influencing factors are significantly identified for all types of EERs, as presented in table 3.13. Similar to a study in the United Kingdom [448], the building characteristics have more explanatory power in terms of EER decisions than household characteristics. In studies focused on residential sectors in China, the household characteristics of education level and age groups, as well as the building characteristics of construction year and floor area, are identified as important factors affecting willingness to pay [204, 253].

Different types of interventions, i.e. structural and informational interventions, can be implemented for different clusters. For instance, if the municipality aims to promote the insulation of the houses, they should probably target the category of the old buildings by supporting grants or subsidies or providing information on the advantages and stages of the renovation process. They could also promote PV panels for newly built dwellings. In Belgium, the ecopack program provides higher subsidies for lower-income groups who plan to implement at least two energy-saving measures [37]. In a study of the United Kingdom homeowners, the importance of financial incentives for old dwellings, which require major renovations, and low-income neighbourhoods are emphasised [480]. Based on a study in China, people adopt energy-efficient technologies with full subsidies rather than separate renovations supported by a partial subsidy [253]. Due to the high potential energy cost savings in old dwellings, the importance of financial incentives is discerned for low-income Canadian homeowners [154].

TABLE 3.13 Contextual, personal, and motivational factors per type of EERs.

Type of EERs	Group	Renovators	Potential renovators
Double glazing	Contextual factor	(a) Building characteristics (construction year: <1980), type of other renovations: repaired/replaced window frames) (b) Household characteristics (income: lower-income), household composition: family with children)	(a) Building characteristics (energy label: F, G, D) (b) Household characteristics (high-income group, household composition: older household)
	Personal factor	_	Deliberately reduce gas and electricity
	Motivational factor	To improve comfort	To improve comfort
		To reduce noise	To reduce noise
		To resell house	Due to maintenance, etc.
Insulation	Contextual factor	(a) Building characteristics (construction year: 1945–1959, 1960–1969)	(a) Building characteristics (construction year: 1945–1959, building type: row houses)
	Personal factor	- Deliberately reduce energy consumption - Awareness of energy consumption	_
	Motivational factor	To improve comfort	To improve comfort Due to maintenance
Solar PV panel	Contextual factor	(a) Building characteristics (energy label: higher e.g. A, building type: detached houses), type of other renovations: replaced/repaired roof/windows frame) (b) Household characteristics (age: older, household composition: family with children)	(a) Building characteristics (construction year: newer) (b) Household characteristics (household composition: non-family, education: higher)
	Personal factor	- Deliberately replace non-energy-efficient devices with efficient ones and reduce energy consumption -Perception of electricity consumption compared to others: perceived higher	Deliberately reduce energy consumption
	Motivational factor	- Saving energy costs -For the environment, etc.	-Saving energy costs -To increase house value -For the environment, etc.
Sustainable heating	Contextual factor	(a) Building characteristics (construction year: 1990–1999, 2000–2009, energy labels: F, G, etc., building type: apartments and semi-detached houses) _	(a) Building characteristics (construction year: newer) (b) Household characteristics (lower-income group and younger groups)
	Personal factor	Deliberately reduce energy consumption	Awareness of energy consumption (well-aware)
	Motivational factor	Due to maintenance	Due to maintenance for the environment

Based on the results of the current study, homeowners who change their behaviour deliberately by using less gas/electricity consumption, for example, are more willing to conduct EERs. The local authorities can target this group of households first. This group can share their knowledge and experiences with other groups. In this way, distributing information regarding the EERs would be more straightforward. In a study in the United Kingdom, the information from the social network increases the probability of adopting energy efficiency renovations by households [290]. In the Netherlands, energy commissioners and energy ambassadors, who live in the same neighbourhoods as the residents, actively contribute to making their neighbourhoods more sustainable by initiating programs or helping their neighbours renovate the buildings more efficiently in terms of energy. These actors require the support of public authorities in facilitating the renovation process by, for instance, loans, subsidies, etc.

In terms of motivational factors, “improving the comfort and maintaining a good physical and structural conditions of house” are identified as strongly important influencing factors for almost all types of EERs except solar PV panels. For the latter, cost savings on energy bills and reducing environmental impacts are significantly identified. Earlier studies identified the importance of these motivational factors in European countries [39, 78, 291, 295, 443, 480]. Therefore, “improving comfort” performs better as a promotional message to the homeowners compared with other messages related to energy efficiency. Furthermore, to achieve the highest energy savings, the responsible organisations must reach homeowners conducting home maintenance and renovations and integrate EERs with these activities. Persuading a homeowner to add some energy-efficient renovations when conducting general maintenance can be a behavioural intervention.

3.6 Summary and Conclusions

The current study aimed to identify behaviour-influencing factors on the energy-efficient renovation (EER) decisions of homeowners in the Netherlands. Applied behavioural studies are reviewed to determine the main influencing factors. The scope of this study is restricted to the specific classes of behaviour-influencing factors, i.e. contextual, personal, and motivational factors. Logistic regression analyses are conducted to examine the impact of these factors on EERs. Four types of EERs are investigated: double glazing, insulation, PV panels, and sustainable heating. These measures are the most popular ones among renovators and potential renovators. A recent dataset, the Netherlands housing survey energy module 2018 [415] released by the Ministry of Interior and Kingdom in collaboration with Statistic Netherlands (CBS), is used as the source of data.

Our empirical study provides pieces of evidence to support the importance of a number of *contextual factors*, e.g. household and building characteristics, especially construction periods, and energy labels. This is in accord with previous studies across different countries that have shown the importance of building and household characteristics on EER decisions. The results also showed that EERs are interrelated with other types of renovation. These results indicate that the preferred type of EER depends on the building and household characteristics. Therefore, responsible organisations can use different clusters of houses in promoting specific types of EERs.

The *personal factors* of awareness of energy consumption, perceived energy consumption compared to other households, perceived degree of efficiency in consuming heating energy, etc are mentioned in the behavioural literature. In the regression analysis, the variables of "deliberately changing the behaviour to energy consumption", "deliberately replacing the non-efficient devices with efficient ones", and "perception of households regarding energy consumption compared to others" are included to examine the importance of this group of behaviour-influencing factors in EERs. For all types of EERs, these specific influencing factors are identified as statistically significant, especially for PV panels. In regression analysis, awareness of energy consumption and the importance of energy efficiency behaviours are the indicators of moral obligations. As explained in the literature review, this conclusion is also valid for countries with similar institutional structures, such as Norway. The importance of these factors can be examined in different countries for future studies. For all types of EERs, at least one of these personal factors is significantly identified for renovators or potential renovators. Responsible organisations can first target groups with a higher probability of EERs to promote energy-efficient dwellings. The spread of knowledge and experiences of different types of EER implementation would then be facilitated.

Different types of *motivational factors* are identified as highly significant per type of EER. For instance, in the case of double glazing, the social motivation for renovators to improve comfort is significantly identified, and for PV panels, the economic motivation to save on energy bills is identified. These findings, specifically for energy-efficient technologies related to solar PV panels, are also in accordance with previous studies internationally. The main motivational factors need to be considered in promoting different types of EERs by responsible authorities.

The theoretical framework of this study is validated by the large sample size of the energy module 2018. Based on this method, the importance and the scale of the effects of behaviour-influencing factors on EERs are identified in the current study. Considering the validation of the theoretical framework with a large sample size, the efficacy of the method in this study is approved. The theoretical framework can be applied for future studies. The outcomes of this research can facilitate the design by public authorities in the Netherlands of more effective policy interventions for different household groups and categories of dwellings per type of EER.

Limitations of the current study and future research

The results of the current study are restricted to the available data from the energy module 2018. This survey is a representative sample of the residential sector in the Netherlands. The list of contextual and personal factors in the literature is more extensive, and few influencing factors are investigated in this study. For instance, the hassle factors were not covered in the energy module 2018. For future studies, these variables can be collected by conducting surveys. This study focuses on the Netherlands, with specific building and household characteristics. The theoretical framework can be examined with similar datasets from other countries. In this way, the robustness of the results can be examined. For future studies, the next step would be exploring other types of cognitive biases influencing EER decisions. The cognitive biases can cause inaction, delay, and unstable decisions. The behaviour of households towards EERs could be better predicted by considering the cognitive biases [170, 183]. For instance, risk aversion and loss aversion are important cognitive biases for any type of investment. Analysing the impacts of these cognitive biases on energy efficiency investment necessitates a more complicated model.
Due to the lack of sufficient data for different types of sustainable heating systems, the parameters of the logistic regressions are estimated for all types of sustainable heating systems (e.g., high-efficiency boilers and heat pumps) in one equation. However, investment costs, technological readiness, and information differ for heat pumps compared to other energy-efficient boilers. In the case of heat pump, it is expected that the higher income groups, the more energy efficient houses and the households with higher awareness of energy consumption are more likely to install heat pump than others.

4 Cognitive biases: isolation, certainty, endowment, and reflection effects

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Note: The previous chapter evaluated more comprehensively the behaviour-influencing factors on four types of energy efficiency renovations: double-glazing, insulation, solar PV panel, and sustainable heating system. The importance of personal factors including cognitive biases was clarified using the main findings of the previous study. Still, very few studies investigated empirically the impacts of cognitive biases on the energy efficiency renovation decisions. This chapter compares the expected utility theory (a rational decision-maker) and cumulative prospect theory (an irrational decision maker). In this approach, it can be clarified which model/s (EUT or CPT) can predict more accurate the decision behaviour of homeowners regarding the energy efficiency renovations. In this chapter, the cognitive biases include the reference dependence, loss aversion,diminishing sensitivity, and probability weighting. Data for these analyses are extracted from the Netherlands energy modules 2012 and 2018. These datasets contain 2,784 and 2,878 homeowners in the Netherlands.

ABSTRACT

Retrofitting residential buildings can help mitigate the effects of climate change. Cognitive biases are systematic deviations from rationality in decision making and can lead to inaction, delay, and uncertain decisions. Understanding the cognitive biases involved in residential renovation decisions and developing interventions to overcome them can help increase residential renovation rates. Despite their importance, few studies have examined the impact of cognitive biases on energy retrofits. The question addressed in this study is: “Can accounting for cognitive biases improve the prediction of homeowners’ actual investment decisions, and how can the outcomes be used to recommend potential behavioural interventions?”.

Expected Utility Theory (EUT) and Cumulative Prospect Theory (CPT) are compared to evaluate which model(s) more accurately describes actual decision-making behaviour regarding energy retrofits. The EUT assumes a rational decision maker. The CPT is a quantitative model that assumes a decision-maker operating under risk and uncertainty and subject to the cognitive biases of reference dependence, loss aversion, decreasing sensitivity, and probability weighting. The influences of cognitive biases on energy retrofit decisions can be quantified if the relative performance of CPT versus EUT is more accurate. The data for these analyses come from housing surveys conducted in the Netherlands in 2012 and 2018, which also collected data on energy modules. 2,784 and 2,878 homeowners were surveyed, respectively. The model is validated by estimating the coefficients of EUT and CPT and identifying the similarities and differences between the results of the two datasets. Before estimating the parameters, four household clusters are identified using grey relational analysis and the K-Means cluster. For the first time, the EUT and CPT parameters are estimated for four clusters and two energy retrofits, double glazing and insulation, using a genetic algorithm because the equations are nonlinear. The results confirm that CPT provides a better description of the actual decision behaviour than EUT using the two previously established initial values of Hackel, et al. [183] and Layard, et al. [258] as well as the parameters estimated by the genetic algorithm. In the latter case, CPT correctly predicts the decisions of 86% of homeowners to renovate their homes to be energy efficient or not. EUT, on the other hand, overestimates the number of decisions to renovate: it incorrectly predicts retrofit for 52% of homeowners who did not renovate for energy efficiency reasons. Using the estimated parameters of CPT, the cognitive biases of reference dependence, loss aversion, diminishing sensitivity, and probability weighting can be clearly seen for different target groups. The groups with the highest average incomes and house values had the highest loss risk aversion parameters. These households invested more in installing insulation and double glazing.

KEYWORDS Energy efficiency renovation; Cumulative prospect theory; Expected utility theory; Cognitive bias; Insulation; Double-glazing

4.1 Introduction

Two hundred countries have agreed to the Paris Climate Agreement, which states that global temperatures should be less than 2C and ideally less than 1.5C above the pre-industrial era baseline. Energy inefficient buildings account for about 75% of the EU building stock. EU countries need to double their retrofit rates if they are to achieve the energy and climate targets set by the EU Commission. In the Netherlands, the housing stock consumes a large amount of natural gas, which accounts for almost 71% of the country's total energy consumption. The Dutch government has therefore set a target to eliminate natural gas as an energy source in this sector by 2050. The technical and financial solutions to improve the rates are in place, but homeowners are not using them as much as expected.

Recent research suggests that cognitive biases are important factors influencing home investment behaviour [88, 112, 478]. Cognitive biases are systematic deviations from rationality in decision making and can lead to inaction, delay, and unstable decisions. Understanding the cognitive biases involved in retrofit decisions and developing interventions to overcome them can help increase retrofit rates. Often, homeowners choose not to renovate due to risk aversion, which explains why energy retrofit rates remain low despite energy targets and policy interventions. In order to encourage homeowners to renovate, it is important to understand their behaviour in terms of their preferences, expectations, experiences and especially their cognitive biases during the retrofit decision process. Despite their importance, few studies have examined the impact of cognitive biases on energy retrofits.

Expected utility theory (EUT) and various variants of prospect theory (PT) are probably the most widely used models for evaluating decisions under risk. EUT assumes a perfectly rational individual who maximises the highest expected utility. In contrast, Cumulative Prospect Theory (CPT) describes what occurs in a situation rather than what should occur. This theory considers the influencing factors that lead to less optimal, less rational decisions. CPT offers potential explanations for many cognitive biases and allows for the quantitative study of these biases. CPT considers the cognitive biases of reference dependence, loss aversion, diminishing sensitivity, and probability weighting [231, 371, 451]. Policy makers can benefit from quantifying cognitive biases because the effectiveness of policies can be subsequently analysed given the presence of cognitive biases.

In a very recent study, Rockstuhl et al. [379] mentioned that volatile future energy cost savings is one of the main barriers to implementing energy retrofits. The authors applied the EUT to investigate the investment decisions using the averaged data of German commercial buildings. The highest optimal investment amount is achieved when decision makers aim to maximise energy cost savings compared to the investment-only perspective (considering expected wealth in the future, as well as related perceived risk). The use of CPT has the potential to improve the results of this study by accounting for cognitive biases. The impacts of behavioural biases on energy efficiency investments were investigated by Hackel, Pfosser, and Trankler [183]. The authors used the original specifications by Tversky and Kahneman [451] and compared the EUT and CPT results based on different scenarios.

Few studies have examined energy efficiency investments using CPT [170, 183]. Empirical investigations of the parameters of CPT have not been conducted for energy efficiency investments in previous studies. This study aims to investigate the impact of cognitive biases on energy retrofit investment decisions. To achieve this goal, the models with and without cognitive biases are compared. The questions to be answered by our study are as follow: (a) Whether CPT describes the actual decision-making behaviour more accurate compared to EUT in the context of energy efficiency investments?, (b) Which cognitive biases significantly determine the Dutch homeowners' behaviours towards energy efficiency investments?, (c) Whether CPT parameters vary for different groups of individuals and types of energy efficiency investments?, and (d) How can the results of CPT be used to recommend potential behavioural interventions for promoting the energy efficiency renovations in the Dutch owner-occupied sector?

We are the first to empirically estimate the parameters of CPT. The parameters of EUT and CPT are estimated from actual data to avoid potential problems associated with assumed responses, such as not accounting for cognitive biases [196, 472]. The energy modules of the 2012 and 2018 Dutch household surveys are used to investigate the parameters of CPT in terms of predicting the actual behaviour of homeowners in their decisions to renovate or not. The approach used in this study is innovative in several ways: (a) the EUT and CPT parameters are estimated for 2,784 and 2,878 homeowners, respectively; previous studies have examined only one building type and individual homeowners (e.g., [183]); (b) homeowners are grouped based on building and household characteristics so that different parameters are estimated for each group of households; and (c) two types of energy retrofits, insulation and double-glazing, are examined from actual data using the 2012 and 2018 energy modules.

This article is organised as follows: cognitive biases and behavioural interventions are discussed in section 4.2. Section 4.3 describes EUT and CPT. Section 4.4 explains the data sets and research methodology. The results of the analyses, discussion, and conclusions are presented in sections 4.5, 4.6, and 4.7, respectively.

4.2 Review of earlier studies on cognitive biases and behavioural interventions in the energy efficiency literature

4.2.1 Overview of cognitive biases in the energy efficiency literature

The energy efficiency gap shows the difference between the theoretical potential energy efficiency and the actual achieved energy efficiency. Neoclassical theory of economics explains the existence of the energy efficiency gap through market failures, environmental externalities or imperfect information. In contrast, behavioural economics attributes energy efficiency gaps to systemic biases, such as high uncertainty about future energy savings [36]. The determinants of the energy efficiency gap are examined in classical, institutional and behavioural economics literature by Gillingham and Palmer [165]. These determinants are shown in table 4.1. Hackel, Pfosser, and Trankler [183] compared expected utility theory and prospect theory, following the work done by Mayer [180, 287]. Based on cumulative prospect theory, the behavioural biases of reference dependence, loss aversion, diminishing sensitivity/risk aversion, and probability weighting/uncertainty explain the energy efficiency gap. Furthermore, the energy efficiency gap is determined by high sunk costs and uncertainty of energy prices. More importantly, loss aversion influences investment decisions drastically, compared to other cognitive biases.

TABLE 4.1 Determinants of the energy efficiency gap [165]

Category	Factors influencing the energy efficiency gap			
Behavioural anomalities and failures	Non_standard preferences[11]: self-control problems, reference -dependent preferences	Non_standard beliefs: systematic incorrect beliefs about the future	Non_standard decision making: limited attention, framing, sub-optimal decision heuristics	
Market Failures	Imperfect information, regulatory failures	Principal-agent issues	Credit constraints	Learning by using: no evidence for energy efficiency technologies
Other reasons	Transaction Costs, Uncertainty	Consumer Heterogeneity	Rebound effect	because of engineering calculation, e.g. not including the interactions between different investments

The barriers from individual, organisational, and institutional perspectives are evaluated for the construction of green buildings in the United States by Hoffman and Henn [197]. Two main theories of behavioural economics are adopted: (1) bounded rationality: individuals are restricted in their ability to achieve pure rationality; and (2) heuristics thinking: individuals rely on simplifying strategies, which cause a wide variety of decision-making biases. For individuals, the following barriers are considered: (a) over-discounting the future; (b) ego-centrism; (c) positive illusions; (d) presumed associations; (e) mythical fixed-pie bias; and (f) environmental literacy. The authors proposed the following strategies to overcome the decision-making biases: issue framing, targeting the right demographic, education, structural and incentive change, compensating risk, green building standard improvements, and tax reform.

Klotz et al. [245] examined the *anchoring effect* on the energy performance goals of commercial buildings in the United States. Three surveys were conducted. The first four questions asked about benefits and incentives for energy consumption reduction. In each of these surveys, identical questions were asked, but with different energy consumption reductions, thereby creating different anchors. One survey arranged an anchor of 90% energy consumption reduction over standard practice; one arranged a 30% anchor; and one set no anchor. At the end of the surveys, participants exposed to different anchors were asked to set an energy efficiency target for a new project. Participants exposed to either the 90% energy consumption reduction anchor or no anchor set higher targets. Therefore, building rating systems

11 Non-standard preferences disregard the standard neoclassical economics theories assumptions of self-control problems, reference dependence, and social preference.

that only support incremental energy improvements may accidentally generate low anchors and, thereby, discourage more advanced energy performance goals that are both technically and economically feasible. In an analytical framework study, Klotz [244] indicated that cognitive biases are one of the main hindrances to achieving sustainability targets of commercial buildings in the United States. Professional bias and group thinking bias were specifically identified in the study. *Motivational framing*, e.g. achieving a healthier neighbourhood by using less greenhouse gases, changes behaviour more than *sacrifice framing*, e.g. getting used to driving less, turning off the lights and reducing the heat. These conclusions were based on a survey among 1,000 householders in Ontario, Canada [162]. Taranu and Verbeeck [432] highlighted the role of both rational and heuristic thinking in explaining pro-environmental behaviour. The results verified that homeowners' positive arguments in favour of energy retrofit are mostly rational, and that negative arguments are mainly heuristic. In a very recent study by Good [170], a behavioural economics model was developed to evaluate the impact of behavioural biases on reducing energy consumption for a demand-responsive electricity system. Among biases, *the endowment effect and the time-discounting* were considered. These biases influence the demand-response provision, particularly when the demand of an entity is high.

4.2.2 Overview of behavioural interventions in the energy efficiency literature

The household behaviours can be influenced by behavioural interventions and nudge tools. The current study also focuses on proposing potential behavioural interventions using the results of CPT for different target groups of households and buildings. Osbaldiston and Schott [344] and Abrahamse et al. [7] reviewed articles and provided a list of interventions targeting the householder's behaviours with regard to energy. They categorised them into: (1) convenience: easy and prompt interventions; (2) information: information on justifying behaviours and guidance on changing behaviours; (3) monitoring: feedback and rewards; and (4) social influence: social modelling, cognitive dissonance, commitment and setting goals. Many of these interventions change the context in which the behaviour takes place, e.g. smart meters provide live information about the current and accumulated energy consumption of a household. Context change is the core pillar of the 'nudge' tools.[12] These tools are generally similar to behavioural interventions [193].

12 "Libertarian paternalism". Nudge tools are policies designed to encourage individuals toward better choices without restricting their freedom [191].

Thaler and Sunstein [434] used the term ‘nudge’ and defined it as ‘any aspect of the choice architecture that predictably alters people’s behaviour, without forbidding any options or significantly changing their economic incentives’ [p.6]. A nudge can also be seen as a tool to modify people’s choices, without removing or changing the number of choices. For example, changing the default setting leads to different choices by households. In an experiment, two default choices of ‘green’ and ‘grey’ utility electricity providers were suggested to two groups of households. People in the green utility group were more likely to choose this default option, compared to other groups [5]. These types of behavioural interventions and nudges are not widely covered in ongoing studies.

Frederiks, et al., [147] extensively reviewed cognitive biases and behavioural anomalities, in predicting household behaviours with regard to energy consumption. The most prevalent biases were status quo bias, loss and risk aversion, sunk-cost effects, temporal and spatial discounting, and availability bias. Additionally, psychological factors such as normative social influence, intrinsic and extrinsic rewards, and trust significantly change household behaviours with regard to energy use. See also [342]. In addition to the most frequent biases, more effective policies in terms of energy consumption were attributed to each bias. Table 4.2 shows the behavioural biases, definitions, and associated policies. In similar studies, taking account of behavioural biases when designing effective environmental and climate change policies is recognised as being crucial [177, 462]. Providing transparent information stimulates energy saving behaviour among households, and giving feedback can considerably reduce the energy bills of households [27]. Dietz, et al., [95] proposed an integrated framework from economic, engineering, behavioural and social science, for designing energy policies that aim to increase the energy efficiency of the residential sector. Households use cognitive shortcuts and different mental considerations in making their decisions. Energy policies need to concentrate on the decisions with the highest impact on energy consumption, by the highest number of capable households with the highest probability of making changes.

TABLE 4.2 A list of biases, definitions and the policy implications influencing the energy consumption.

Biases	Definition	Policy implications
Status quo bias and defaults	people are not willing to change and prefer to go with the flow of default settings, even where other options may have better outcomes.	Applying the energy related practices with easy and effortless changes to the default settings, e.g. introducing the energy efficient option as default rather than encouraging them to choose energy efficient option between others.
Satisficing	Applying only the effort needed to achieve a satisfactory rather than an optimal result	Inessential complexity and sensory overburden need to be avoided by framing messages in a clear, concise and comprehensible format.
Be loss averse	Considering losses more with the same size gains,	Emphasizing on the cost/ loss reductions of using energy efficiency measures rather than energy savings
Be risk averse	People are more likely to engage in a risky behaviour to avoid a certain loss rather than to engage in a similarly risky behaviour to obtain a comparable gain.	Focusing on low-risk, safe, stable, and secure energy saving measures and investments
Sunk cost effects	After purchasing appliances, people insist to use them even if better choices become available.	Reduce the importance of old energy efficient investments and emphasize on the costs of any inefficient investments
Temporal discounting/ spatial discounting	Less valuable further away in time/space. Avoiding on expenses on energy efficiency appliances if the benefits are further away in the future.	Emphasise to the longer-term payoffs of energy consumption
Conform to social norms	The behaviours and attitudes of other people always influence peoples behaviours, such as herd behaviour, the Bandwagon effect.	Formulate energy-saving practices socially desirable behaviour
Be motivated by rewards and incentives	The incentives lead to more behavioural responses.	Use non-monetary rewards such as praise, recognition and social approval
Free-riding effect	Tendency to contributing less for public good when possible and believing that others are contributing less.	Making a group and showing the participations of other people in energy saving activities
Trust	A trustworthy professional is an effective source to influence the decision-making process.	Providing information that originates from a high-credibility source (e.g., public service commission)
Availability bias	People usually use the available information	Specifying the well-publicised popular energy-saving behaviours and favourable to consumers

4.2.3 Review of energy-efficiency literature on the main influencing factors and barriers of energy retrofits

Previous studies are reviewed to investigate the importance of identifying the barriers for specific groups of households. According to the literature review [56, 109, 480], the household characteristics, socio-demographics, property characteristics, and salient events (e.g. moving house) determine EER decisions. For instance, in a study of eight European countries, considerable differences in adoption of energy-efficiency technologies were recognised, among different income groups of households. The willingness to pay is considerably lower for the lowest income groups and all types of energy-efficient technologies [396]. In another study, the effectiveness of subsidy programs was investigated by Lihtmaa, et al., [265]. Subsidies were assigned equally for all residents. However, an unequal distribution occurred on a regional basis. Low-performing regions gained a lower proportion of national subsidies, leading to the inequalities between regions increasing further, over and above current socio-economic differences.

Abreu, et al., [8] emphasised the importance of designing specific policies for different groups of homeowners, with regard to energy-saving retrofits. In addition to household and building characteristics, daily activities and social practices are identified as important influencing factors. The authors focused on different age groups of homeowners in single-family dwellings. They examined which home-related activities and social practices drive this group of households to conduct energy-efficiency retrofits. The authors concluded that younger homeowners appeared to be more environmentally conscious and implemented 'little-by-little' energy retrofits. The motivational factors for older groups must be stronger, despite their higher incomes. The use of framing is also recognised: when energy-related retrofits are linked with other aspects of the home, such as aesthetics and indoor comfort, the likelihood of those retrofits being undertaken increases. In a study of German homeowners, installation of insulation was assessed, to examine the effect of policy interventions for this group of households [148]. For this type of energy-efficiency retrofit, the policies focused on wall insulation. Furthermore, the homeowners' decisions on energy-efficiency retrofits were highly dependent on their financial resources, age and attitude towards insulation, as well as the structural conditions of the walls. Compelling new homeowners to insulate their walls within the first year can potentially increase the total insulation rate by up to 40%.

Another group of studies focused on multi-family dwellings [52, 65, 96, 356, 433]. Dodoo, et al., [96] analysed the cost-effectiveness of various energy-efficiency measures, such as insulation, improved windows, or a glass-enclosed balcony, for a typical 1970s multi-family buildings in Sweden. The results indicated that the highest energy saving for a single measure is achieved by improved windows. Furthermore, the cost-effectiveness showed sensitivity to both the real discount rate and energy price growth. The energy-saving potential of deep energy-efficiency retrofits, such as various types of insulation and improved energy-efficient windows and doors, were evaluated for Swedish multi-storey residential building of the 1970s by Tettey and Gustavsson [433]. Energy savings for space heating were significantly increased by the use of energy-efficient windows and doors, balanced ventilation with heat recovery (VHR), and additional insulation to external walls. The benefits of energy-efficiency s, such as insulation, window glazing, and district heating for individuals and national government, were investigated for apartment buildings constructed during the 1970s and 1980s in Estonia [356]. The authors used the net present value (NPV) method to calculate the economic benefits of energy-efficiency s, following the European commission's cost optimality methodology [125]. The authors concluded that energy-efficiency s contributed considerably to economic benefits for both individuals and national governments. These economic benefits would be even higher, if one could place a monetary figure on non-energy benefits whose economic value is difficult to calculate. Similarly, Bonakdar, et al., [52] investigated the cost-optimum level of building fabric elements, of extra insulation thicknesses for considered opaque elements, and different U-values for new windows in a multi-storey Swedish residential building. A variety of different economic outcomes was assessed, by including different discount rates and energy price growth rates. However, the results were not particularly sensitive to changes in the lifespan, to figures of 40, 50 or 60 years. Brown et al., [65] evaluated the economic, indoor environmental quality (IEQ), and environmental aspects of energy-efficiency packages for a Swedish multi-family building. A base case, and two packages with higher initial investment costs and higher levels of energy-efficiency s, were defined for each building. Based on the results, the packages that reduced the energy demand considerably (50% energy reduction) have a higher life-cycle cost. Hence, higher initial investment costs for multi-family dwellings are essential to achieving national and international energy efficiency goals.

Another group of studies evaluated the energy-efficiency for single-family dwellings [215, 276]. In a study for the Nordic countries (i.e. Denmark, Sweden, Norway, Finland), the behavioural, economic, and market-related hindrances to promoting energy-efficiency s of single-family detached houses built before 1980 were analysed. These dwellings are expected to have substantial primary energy saving potential [276]. The identified barriers were: lack of need; lack of regulatory requirements on the energy standard of a renovated building; insufficient information; lack of knowledge/awareness about the energy-efficiency measures and the energy and non-energy benefits; lack of trust; uncertainties among financiers and end-users regarding the energy saving levels; difficulty in measuring the monetary values of non-energy benefits, such as improving quality of life; no agreement on the suitable discount rate; difficulty in controlling the occupants' energy use behaviours; and, finally, difficulty in predicting future energy prices. In the current study, different target groups of households, such as by age or type of dwelling, are investigated, to identify their cognitive biases and recommend potential behavioural interventions for each group of homeowners. In a very recent study, Cristino et al. [87] examined the barriers to energy retrofits in Brazil. The first main identified category of barriers was related to governmental and financial aspects. Residents believe that the government is responsible for the implementation of energy retrofits in the country. The importance of behavioural barriers was also explored. Many households were reluctant to invest because they lacked concrete information about the benefits of energy efficient technologies.

4.3 Expected utility theory and cumulative prospect theory in explaining the individual decision-making processes regarding the energy retrofits

Two psychologist, Amos Tverskey and Daniel Kahneman, developed 'prospect theory' which explains the relation of preferences with regard to attitudes to gains and losses. They won the Nobel memorial prize in economic sciences' for developing this theory and comparing their cognitive models of decision-making under risk and uncertainty to economic models of rational behaviour [231, 451]. This study also uses cumulative prospect theory (i.e., in which a decision-maker irrationally confronts risk and uncertainty) and compares this theory with expected utility theory (i.e., in which a decision-maker who rationally confronts risk). By comparing these models, appropriate model/s that predict the homeowners' decisions about energy retrofits can be examined. The following subsections describe the EUT and CPT theories.

4.3.1 Expected Utility Theory (EUT)

Standard neoclassical theory assumes that individuals behave and make decisions rationally under risk by maximising their expected utility. The formal representation of decision-making under risk is as follows:

$$EUT = \sum_{i=1}^{n} p(X_\mathrm{i}) \cdot u(\varphi_\mathrm{i}) \tag{4.1}$$

Where n shows the number of payoffs, X_i indicates the payoffs, $p(X_i)$ presents the probability of payoffs X_i and u(phi) $_i$) indicates the individual utility of total wealth $(\text{phi})_i$. The total utility is calculated based on the initial wealth and the payoffs (phi $_0$+X_i). The utility function is defined based on equations 2. This utility function indicates the constant risk aversion by individuals [183, 258].

$$u(\varphi_\mathrm{i}) = \begin{cases} \frac{1}{1-\theta} \cdot (\varphi_\mathrm{i}{}^{1\text{-}\theta} - 1) & for \quad \theta \neq 1 \\ ln(\varphi_\mathrm{i}) & for \quad \theta = 1 \end{cases} \tag{4.2}$$

When the EUT is higher with the payoffs. The investment increases the utility and must be implemented.

4.3.2 Cumulative Prospect Theory (CPT)

Few studies have investigated energy-efficiency investments using behavioural economic theory. Previous work mainly used this model and simulated the behaviour by making assumptions regarding the parameters in the model [170, 183]. Hackel, et al., [183] suggested empirical investigations of the parameters of CPT as subjects for future research. The current study aims to examine and verify the CPT parameters empirically. The cumulative prospect theory advances the prospect theory by modifying the possible error of first- order stochastic dominance. Furthermore, CPT enables comparison with EUT. CPT defines a value function that depends on the differences in the payoffs. CPT offers advantages in the quantification of many cognitive biases. CPT mainly covers four cognitive biases as presented in table 4.3:

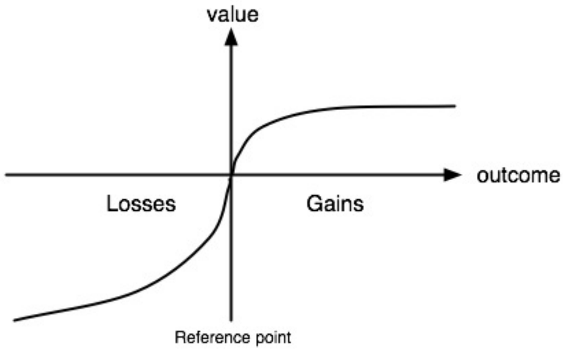


FIG. 4.1 Schematic presentation of the value function for cumulative prospect theory

TABLE 4.3 Cognitive biases of cumulative prospect theory.

Cognitive bias	Definition
Reference dependence	Individual decision-making depends on the difference between the changes in the utility of the current wealth with their reference point or status quo (usually in the past).
Loss aversion	Individuals perceive the value of loss higher compared to the same value of gain.
Diminishing sensitivity	Generally speaking, people prefer to avoid risk given the prospect of a positive outcome (i.e., gain), but the reverse is true given the prospect of negative outcomes (i.e., loss).
Probability weighting	Individuals use the probabilities of the outcomes instead of statistical probabilities and place a lower weight on the average payoffs (the centre of the distribution), but a higher weight on events with low probabilities (the tails of the distribution).

Two functions are defined for positive and negative differences [183, 371, 451]. The value functions are as follows:

$$v(\Delta x_i) = \begin{cases} (\Delta x_i)^{\alpha} & \Delta x_i \geq 0 \\ -\lambda(\Delta x_i)^{\beta} & \Delta x_i \leq 0 \end{cases} \tag{4.3}$$

α and β>0 (usually α, β É 1) indicate the curve for the positive and negative payoffs, respectively. The λ>0 parameter shows the loss aversion, i.e., weighting the loss more than equal gain. For instance, λ equal to 2 means that individual perceives loss twice more than gain.α and β>0 (usually α, β 1) indicate the curve for the positive and negative.

Diminishing sensitivity (i.e., risk avoidance in gain situations and risk seeking in loss situations) are included in CPT. This bias is applied in the model by objective probabilities instead of weighting with their subjective values.

$$w(p(\Delta x_{\mathrm{i}})) = \begin{cases} \dfrac{p(\Delta x_{\mathrm{i}})^{\gamma}}{(p(\Delta x)^{\gamma} + (1 - (p(\Delta x_{\mathrm{i}}))^{\gamma})^{1/\gamma}} & for \quad \Delta x_{\mathrm{i}} \geq 0 \\ \dfrac{p(\Delta x_{\mathrm{i}})^{\delta}}{(p(\Delta x)^{\delta} + (1 - (p(\Delta x_{\mathrm{i}}))^{\delta})^{1/\delta}} & for \quad \Delta x_{\mathrm{i}} \leq 0 \end{cases} \tag{4.4}$$

Different studies validate this functional form [169, 257]. The weighting function uses the objective probabilities p(Δxi) to the subjective/perceived probabilities w(p(Δxi). Two parameters of δ and γ control the curve of the value function. Diminishing sensitivity is incorporated in the model by the parameters of γ and δ between (0,1]. The higher sensitivities are expected for individuals with lower values of γ and δ. Furthermore, larger values for loss δ are expected compared to gain γ as specified by Tversky and Kahneman [451]. CPT differs in weighting cumulative probabilities compared to PT by weighting single probabilities (p(Δxi)). CPT applies weighting to the cumulative probability distribution. There are a few steps in calculating the weight πi (1) ranking the payoffs (ascending), (2) using the probabilities of each payoff, (3) using the right function for positive and negative payoffs, and (4) calculating the differences in neighbouring probability weightings. The weighting for the positive payoffs depends on the probabilities of the payoffs being at least as good as the payoff i and the higher payoffs compared to payoff i. The weighting for negative payoffs depends on the weighted probabilities of the payoffs being at least as bad as the payoff i and the weighted probabilities of the payoffs being worse than payoff i. Equations 8 shows the decision weight πi.

$$\pi_{\mathrm{i}} = \begin{cases} w(p(\Delta x_{\mathrm{i}}) + \ldots + p(\Delta x_{\mathrm{n}})) - w(p(\Delta x_{\mathrm{i+1}}) + \ldots + p(\Delta x_{\mathrm{n}})) & for \quad \Delta x_{\mathrm{i}} \geq 0 \\ w(p(\Delta x_{1}) + \ldots + p(\Delta x_{\mathrm{i}})) - w(p(\Delta x_{1}) + \ldots + p(\Delta x_{\mathrm{i-1}})) & for \quad \Delta x_{\mathrm{i}} \leq 0 \end{cases} \tag{4.5}$$

The equations are valid for:

$$\begin{aligned} \Delta x_{\mathrm{i}} \geq 0 \quad \text{for} \quad k+1 \leq i \leq n-1, \text{ and} \\ \Delta x_{\mathrm{i}} \leq 0 \quad \text{for} \quad 2 \leq i \leq k. \end{aligned}$$

Where k indicates the number of negative payoffs. CPT is calculated by multiplying the decision weight (πi) and value function (v(Δxi)).

$$CPT = \sum_{i=1}^{n} \pi_{\mathrm{i}} \cdot v(\Delta x_{\mathrm{i}}) \tag{4.6}$$

A CPT more and less than 0 indicates a favourable and unfavourable decision, respectively. The values of CPT are not in monetary terms. Although the CPT is originally formulated for one period, the value function can be extended for the long term as well. To achieve this, the status quo, aggregation of future outcomes, and consideration of the time value of money need to be considered. This study uses a multi-period NPV including the status quo (the initial wealth of the individual) to extend the one-period CPT function to the multi-period CPT similar to studies done by Hackel, et al. [52, 125, 183, 356]. Therefore, Δx_i is replaced by NPV in all the formulas (equation 11). Energy-efficiency investments are similar to any other types of investment. An initial financial cost and usually uncertain outcomes are the components of energy- efficiency investments. Therefore, in this case, Net Present value (NPV) is used to evaluate the energy-efficiency investments over the long term. If the total present value of an energy-efficiency investment is higher than the initial investment costs, people might invest in it. The mathematical form of the NPV is:

$$NPV = -I_0 + \sum_{n=0}^{T} \frac{CF_{\mathrm{t}}}{(1+r)^{\mathrm{t}}} \tag{4.7}$$

Where I_0 is the initial investment. T is the lifetime of the energy-efficiency investments. r is the indicator of the time value of money discounted by the interest rate. The following formula is used to calculate the CF_t , cost saving in each period:

$$CF_t = P_t \cdot C_t \cdot \varepsilon + UCB_t \tag{4.8}$$

Where P_t is the stochastic price per source of energy (for instance, for gas it is kWh) for period t. C_t is the energy consumption for period t, and ε indicates the percentages of energy savings per source of energy. UCB_t shows costs and benefits that are difficult to measure and not observable, such as time and effort expended to find reliable information or contractors (i.e., transaction costs) [112, 113]. Regarding the benefits, energy saving is the main and observable benefit of implementing energy-saving measures. This benefit might be calculated more easily compared to other benefits such as enhanced quality of life.

4.4 Methodology

4.4.1 Database

The data of the main variables defined in EUT and CPT models is collected from the Netherlands Household Survey Energy modules 2012 and 2018. This dataset is released every 5-6 years. Table 5.14 shows the datasets of this study

TABLE 4.4 Data sets for the estimation of EUT and CPT parameters.

Datasets	Number of respondents	Variables
Energy module 2012	2784	Time series of energy consumption (2004–2010), energy labels, energy savings in the dwelling stock, building and household characteristics, energy efficiency in the past five years (i.e. insulation and double glazing), planning for energy retrofit in the coming two years, investment costs, the house values. The data regarding the expectation of households are collected using a survey among almost 5000 of buildings.
Energy module 2018	2787	The only difference with energy module 2012 is that the time-series of energy consumption is not included in this new version. - Energy consumption 2018
Eurostat	_	The initial values of the gas and electricity prices in the Netherlands.
Milieu Centraal	_	The initial values for energy saving percentages, initial investment costs.

4.4.2 Methods of analyses

Building and household characteristics significantly influence the energy retrofits according to the previous studies [32, 112, 113, 478, 480]. In this subsection, the clustering method is explained. The cluster of households is defined using building and household characteristics. Before finalising the main influencing factors for clustering the data, more variables were used to define different clusters. However, the identified numbers of observations per cluster are not very well distributed. A sufficient amount of data per cluster is required for examining the parameters of EUT and CPT. Therefore, these variables are removed one by one to evaluate the distribution of data per cluster of households. Based on this investigation, it was found that the variables with so many missing values cause a very uneven distribution of the numbers of observations for different clusters. The appropriate algorithm in case of many missing values is K-mean clustering explained in section 4.5.1. The main building and household characteristics are as follows: (a) building characteristics including building types (multi and single family houses); type of single-family dwellings (detached, two under one roof, middle houses, row houses); type of multi-family dwellings (flat and maisonette); number of rooms; construction period; type of heating system (gas boiler, block or neighbourhood heating, district heating, etc.). (b) household characteristics: number of households; whether relocated or not in the last two years; age; income; and education.

Cluster analysis

The purpose of clustering is to group observations into the classes or clusters, so that objects in the same group have high similarity, and objects in other groups are not alike. 'n' buildings and 'n' households are in the datasets that are called 'instances'. 'm' attributes, i.e. specific characteristics, are defined for each instance. Each instance is assigned to a group. One important step needs to be conducted before the main cluster analysis. The degrees of influence of these attributes differ. For instance, the construction period is expected to influence energy retrofit considerably more than other factors, such as the number of rooms in the buildings. Therefore, a weighting system is needed to consider the importance of different attributes in the clustering process. Furthermore, the values of attributes need to be normalised to prevent two important miscalculations in grouping the instances: (a) most of the attributes have different units of measurement, and the differences between units influence the quality and accuracy of clustering; (b) this weighting system prevents data with large ranges from having more weight than attributes with smaller ranges.

Grey relational analysis (GRA) is conducted to normalise and to identify the weights of different attributes [249, 260, 487, 490]. First, the min-max normalisation is conducted to make the scale of attributes comparable and within the same range. This method of normalisation retains the relationship between the initial data since it performs a linear normalisation. In this study, the new range is defined between [0,1].

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \left(X'_{\max} - X'_{\min} \right) + X'_{\min} \tag{4.9}$$

For categorical variables with meaningful orders, it is essential to make an order and then to assign the values between [0,1].

$$X' = \frac{rank_{\mathrm{i}} - 1}{rank_{\max} - 1} \tag{4.10}$$

Based on geometrical mathematics, grey relational analysis (GRA) is performed to identify the grey relational grades and a grey relational order (i.e., the rank of grey relational grades). These values can show the primary values between the influencing factors and the target variable, i.e. the decision. As mentioned, the influencing factors are defined within two categories of attributes: building and household characteristics. The grey relational grades indicate the degree of the influencing factors on the energy retrofit decision. The advantages of this method are its simplicity and its lack of assumptions regarding the type of probability distributions of the attributes [487]. X and Y indicate the influencing factors and the energy retrofit decision, respectively. To calculate the GRA, these steps are followed: 1) normalisation of the data, 2) calculate the grey relational coefficients using equation 15 (normally alpha=0.5):

$$\xi_{\mathrm{i}}(k) = \frac{\underset{i}{min}\underset{k}{min}|y(k) - X_{\mathrm{i}}(k)| + \alpha \underset{i}{max}\underset{k}{max}|y(k) - X_{\mathrm{i}}(k)|}{|y(k) - X_{\mathrm{i}}(k)| + \alpha \underset{i}{max}\underset{k}{max}|y(k) - X_{\mathrm{i}}(k)|} \tag{4.11}$$

3) compute the grey relational grades 4) rank the obtained grey relational grades, so that the grey relational order can be identified. The grey relational grades are used to weight related attributes in cluster analysis. This grade is between [0,1].

K-Means clustering is used to group similar instances within one group [23, 289, 324, 471]. In this method, no target variable is predicted, i.e., an unsupervised learning problem. Each cluster should have different features: (1) all instances should be very much alike. The sum of squares of distances of each instance from the centroid of a cluster, also called the ’intra cluster distance’, are calculated. In this regard, lower values result in a better cluster; (2) the instances in one cluster should be as distinct as possible from other clusters. The ’inter cluster distance’ is calculated to indicate the distances between clusters. After calculating these two values, the Dunn index is calculated using equation (16). The Dunn index is applied. The values of this index need to be maximised, and a higher value of the Dunn index indicates better clustering. The K-means clustering is an algorithm for minimising the sum of distances between the instances in a cluster with their corresponding cluster centroid [100, 272, 348].

$$Dunn_i = \frac{min(Inter - cluster - distance)}{max(Intra - cluster - distance)} \tag{4.12}$$

A few criteria are used to rely on the clusters by the K-means algorithm: centroids of new clusters do not change in the new iteration; instances stay in the same cluster; and finally, the maximum number of iterations is obtained. It is a challenge to achieve the appropriate size of different clusters in terms of scale. If a cluster is too large, a cluster analysis can be conducted for this specific cluster to make several clusters out of it. Another challenge is when the densities of different clusters differ. Again, the k-means clustering algorithm and the use of a higher number of clusters can be applied to solve this issue. The elbow method is used to determine the optimal number of clusters for each data set. In the elbow method, data clustering is performed several times, in each attempted data is clustered in predefined number of clusters. Then, the sum of squared distanced of each data point from the centre of the corresponding cluster is plotted as a function of the number of clusters. The resulting plot should have a shape of an arm where the number of clusters at the location of the elbow will correspond to the highest Dunn index and indicated the optimal number of clusters [47, 246, 489].

Calculation of the main components of EUT and CPT models

Net present values of energy efficiency investments.

Energy saving depends on gas and electricity prices. Future gas and electricity prices are sources of uncertainty in the NPV model. Therefore, different NPVs are calculated for the same values of energy consumption and energy saving percentages for different paths of energy prices. First, these NPVs are computed for each household per type of energy saving measure in the samples (2,784 and 2,878 instances). The NPVs are used as the inputs for calculating the values of the EUT and CPT.

Predicting the energy prices using "Geometric Brownian Motion".

Energy prices are a source of uncertainty for energy retrofit decisions. As with Hackel, et al. [183] and Postali and Picchetti [360], energy prices are simulated using Geometric Brownian Motion (GBM). The main reason for using this method is the characteristics of energy prices, chiefly the uncertainty of predicting their increase over time. Extended periods of low and high energy costs are both apparent. The GBM contains two important parameters: the long term average of (μ) and the degree of randomness surrounding this average (σ).

$$\delta P_t = \mu \mathrm{P_t} \left(\mathrm{dt} = 1 \ \mathrm{year} \right) + \sigma \mathrm{P_t dW_t} \tag{4.13}$$

Where P_t is the gas price, (μ) is the average trend of the gas price, (σ) is the randomness or volatility of gas prices, and W is the Brownian Motion. The Brownian Motion is the random part of the equation. The W is the result of using the actual continuous-time stochastic process, known also as the Wiener process. W has the standard normal distribution, $W \sim N(0,1)$. Each W is calculated using a standard random variable z by the square root of the time changes. We forecast gas prices on a yearly basis because these are usually decided annually. We calculate 50 energy price paths for each building. A higher number of energy price simulations was not possible, due to computational burdens in terms of time and the capacity of the computer. Hackel, et al., [183] estimated the energy prices for 10,000 simulation runs per year. However, that analysis was performed for only one type of building. In this paper, analyses were conducted for 2,784 and 2,878 buildings. Therefore, it was not possible to create a greater number of energy price simulations.

Probability of each NPV.

For deriving EUT and CPT, the probability of each NPV needs to be estimated. For this purpose, a kernel density estimator (KDE) is employed. This probability density estimator has advantages over other estimators, such as normal distribution. A density estimator is an algorithm which aims to model the probability distribution that generated a dataset. A histogram is a widely-used density estimator for one-dimensional data. The data is divided into different ranges and the number of data is calculated for each range. The advantage of KDE is that it is more precise in terms of estimation of probabilities. The histogram calculates the probabilities for a range and block of data. KDE instead estimates the probability for each point in the dataset. The results are more robust in estimating the actual data characteristics compared to a histogram density estimator [183, 185, 346]. For KDE, a Gaussian kernel is used, which gives more accurate results on the shape of data distribution, and the results are changed less due to the differences in sampling[13]. One input parameter of KDE is the bandwidth. The bandwidth is estimated for each house using the optimisation method, which is incorporated in the Scikit-Learn library in Python 3.[14]

Energy consumption and energy saving.

In the energy module 2012 dataset, energy consumption is provided for 2784 houses and for seven years before collection of the dataset (2004-2010). The data is the official energy consumption for each house, and is not taken from a survey. The average values for energy consumption are calculated. These average values are used as indicators of energy consumption for each household. The energy module 2018 contains the energy consumption for the year 2018. Therefore, the energy consumption for the year 2018 is considered to be the reference for energy consumption of these dwellings. For energy saving, the percentages of energy saving per measure, i.e. insulation, and double glazing, are collected using reliable sources such as Milieu Centraal, and Netherlands Enterprise Agency (RVO). Similar to Hackel, et al., [183], UCB = 0 is assumed, i.e., the unobserved benefits and costs compensate for each other.

13 we used sklearn package in python 3 because of its flexibility and efficiency. This package can estimate KDE in multiple dimensions with one of six kernels and one of a couple dozen distance metrics. Because KDE can be fairly computationally intensive, the Scikit-Learn estimator uses a tree-based algorithm under the hood and can trade off computation time for accuracy using the atol (absolute tolerance) and rtol (relative tolerance) parameters.

14 GridSearchCV implements a “fit” and a “score” method. It also implements “predict”, “predict_proba”, “decision_function”, “transform” and “inverse_transform” if they are implemented in the estimator used. The parameters of the estimator used to apply these methods are optimized by crossvalidated grid−Ssearch over a parameter grid.

4.5 Results

4.5.1 Cluster analysis

To achieve more meaningful clusters, weight factor are used for different attributes based on their grey relational grades. The grey relational grade shows the relative importance of factors in determination of the outcome. Therefore, factors with higher grey relational grades should be given more weights in formation of clusters. The results of grey relational grades are presented in Table 4.5 and 4.6. For energy module 2012, building characteristics: type of single family/multi-family dwellings, year of construction, and type of heating system, show a higher correlation to decisions compared to household characteristics. Regarding household characteristics, the number of people in the households and relocation in the last two years are important factors. For energy module 2018, the type of building has the highest degree of correlation with investment decisions, followed by the household composition (i.e. one person, a family with or without children, etc.).

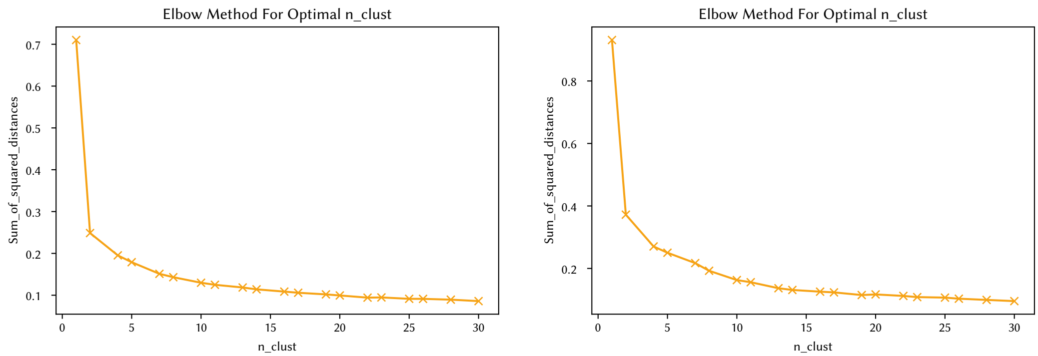
TABLE 4.5 Grey relational grades for each attribute using the energy module 2012.

Target variable	Number of people	Household relocated	Age	Income	Type of house (S/M)	Type of multi-family house	Construction year
Energy efficiency decision	0.6014	0.6176	0.5750	0.5203	0.6537	0.7345	0.6252
	Type of heating system	Building type, e.g. detached houses	Gas	Electricity	Number of rooms	Type of single family house	
	0.6216	0.5722	0.5323	0.5576	0.5222	0.5605	

TABLE 4.6 Grey relational grades for each attribute based on the energy module 2018.

Target variable	Number of people	Household relocated	Age	Income	Type of house (S/M)	Type of multi-family house	Construction year
Energy efficiency decision	0.5479	0.5780	0.5433	0.5879	0.5631	0.6964	0.5384
Household composition	Building type	Gas	Electricity	Number of rooms	Type of single family house		
	0.6905	0.5507	0.5052	0.5235	0.5378	0.6044	

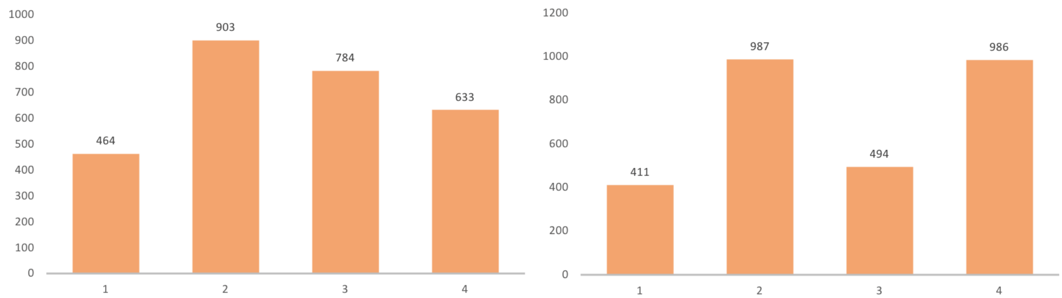
The K-means clustering method is used to cluster similar instances in one group. Considering the number of instances and their distribution, the k-mean method is more suitable for the dataset used in this publication. The algorithm disregards the missing values, and the calculation is completely based on the actual observations. The cluster analysis is conducted from one to thirty clusters. Therefore, the population per cluster and the distribution of instances per cluster can be depicted. The elbow method is used to determine the optimal number of clusters for each data set. In the elbow method, data clustering is performed several times, in each attempted data is clustered in predefined number of clusters. Then, the sum of squared distanced of each data point from the centre of the corresponding cluster is plotted as a function the number of clusters. The resulting plot should have a shape of an arm where the number of clusters at the location of the elbow will correspond to the highest Dunn index and indicated the optimal number of clusters [47, 246, 489]. Using the elbow method, the number of clusters equal to 4 has the highest Dunn index for two datasets of the energy modules 2012 and 2018. Furthermore, this number of clusters contains the most appropriate population per cluster, as well as distribution of instances across different clusters.



(a) The energy module 2012 (b) The energy module 2018

FIG. 4.2 Elbow Method for the optimal number of clusters

The clustering analysis is performed with an in-house python script. The number of observations is shown in Fig 4.3. The optimal values of the squared sum of the cluster analysis is equal to 0.19 and 0.27 using the energy modules 2012 and 2018, respectively. Later, the characteristics of these clusters are investigated. The cluster analysis is an unsupervised learning process, and these clusters are grouped without connection to any type of target variable.



(a) The energy module 2012 (b) The energy module 2018

FIG. 4.3 Population per cluster

After clustering all data point into the optimal number of clusters, in tables 4.7 and 4.8. The number of conducted energy retrofit measures are compared in different clusters per type of retrofit. Tables 4.7-4.10 indicate the characteristics of different clusters using the average values. It can be seen that cluster number 2 in module 2012 and cluster number 8 in module 2018 have the highest number of implemented energy retrofits. These clusters have highest average income and value of the house among other clusters. The occupants of these clusters are around 55 to 60 years old. In terms of construction year, the average year is equal to 1988 and 1969 in clusters 2 and 8, respectively. Conversely, the cluster with the lowest number of installed energy-saving measures has the lowest house values and household incomes.

TABLE 4.7 Different characteristics of four clusters - National Household Survey energy module 2012.

Cluster	Insulation	Boiler	Double glazing	PV_panel	Number_energy_saving	House_value	Income
1	25	104	68	1	198	217,445	47,708
2	160	329	223	38	750	353,921	65,922
3	112	265	205	14	596	262,960	56,292
4	136	188	171	15	510	240,183	58,932

TABLE 4.8 Different characteristics of four clusters - the energy module 2012.

Cluster	Number_of_people	building year	EI	Type of house	Number_of_rooms	Relocated	Age
1	1.7	1994	1.81	multi_family	3.4	0.153	54.5
2	2.6	1988	1.84	single_family	5.4	0.016	59.8
3	2.3	1984	1.89	single_family	4.9	0.005	60.7
4	3.3	2004	1.71	single_family	4.9	0.210	38.0

TABLE 4.9 Different characteristics of four clusters - the energy module 2018.

Cluster	Insulation	Boiler	Double glazing	PV_panel	Number_energy_saving	House_value	Income
5	79	121	79	67	346	256,437	43,182
6	232	311	247	223	1013	263,199	69,418
7	72	136	72	19	299	257,196	58,097
8	258	317	243	285	1103	370,734	84,051

TABLE 4.10 Different characteristics of four clusters - the energy module 2018.

Cluster	Number_of_people	building year	EI	Type of house	Number_of_rooms	Relocated	Age
5	1.08	1964	1.71	single_family	4.7	0.087	56
6	2.79	1972	1.66	single_family	5.1	0.129	48.5
7	1.64	1959	1.68	multi_family	3.5	0.224	51.5
8	2.6	1969	1.6	single_family	5.7	0.068	55

This study focuses on households with only one or no energy-saving measure for estimating the EUT and CPT. The main reason for this choice is that it is not possible to separate the effect of various energy efficiency measures in case of multiple energy retrofits.

4.5.2 Variables in calculating the Net Present Values (NPVs)

NVP includes the effects of all costs and benefits throughout the life time of a measure. Most of the cost is paid upfront while the benefits are accumulated later on. To be able to calculate the benefits of each energy efficiency measure in terms of monetary savings by consuming less energy, the energy consumption in case of no energy saving measure, the expected percentages of energy saving per type of energy-saving measure, and the future energy prices must be known

Predicting gas prices

Knowing the the long-term price trend μ, and price volatility σ, different possible trajectories can be estimated gas price in the future using geometric Brownian motion. The values for the $\mu = 5.7\%$, and $\sigma = 17\%$ are obtained from historic data from the Eurostat dataset. This study aims for the long-term evaluation of investment decisions; therefore, energy prices are estimated for 30 years. Gas prices are simulated 50 times per year. Fig 4.4 shows 10 examples of gas price predictions over 30 years. Given bi-yearly data, 60 instances are generated to compute data for 30 years.

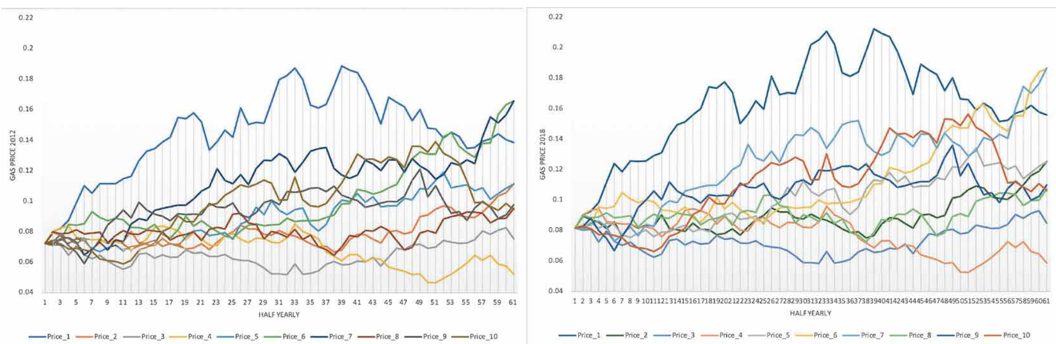


FIG. 4.4 Examples of gas price predictions over 30 years

Energy-saving measures

Table 4.11 shows the total numbers and percentages of installed insulation and double glazing for houses with one energy saving measure. To calculate the energy savings for each measure, the expected energy savings per type of energy saving measure is needed. The expected energy savings are collected from reliable data sources such as the Netherlands Environmental centre and the Netherlands Enterprise Agency (RVO). From this source, the expected energy savings of insulation and double glazing are 12% and 14%, respectively. These percentages are multiplied by average actual gas consumption to calculate the average energy saving per type of energy-saving measure.

TABLE 4.11 Total numbers and percentages of energy-saving measures per cluster from the energy module 2012 and 2018 (households with one energy-saving measure).

2012					2018				
	Insulation		Double glazing			Insulation		Double glazing	
name	numbers	%	numbers	%	name	numbers	%	numbers	%
cluster 1	2	0.43	26	5.60	cluster 5	24	5.84	21	5.11
cluster 2	24	2.66	67	7.42	cluster 6	57	5.77	68	6.89
cluster 3	24	3.06	74	9.44	cluster 7	22	4.45	24	4.86
cluster 4	25	3.95	50	7.90	cluster 8	55	5.58	40	4.06

Energy efficiency investment

In the dataset, households provide information on the investment costs of energy-saving measures. The information is not available for all households. The average investment cost per cluster of households is computed in place of the missing household cost. The outliers, such as investment costs less than 100 euros, were removed. Previous studies identify high upfront costs as one of the main barriers to conducting energy retrofits [113, 183, 199]. Therefore, the investment costs, including subsidies and no-subsidies, are used to test the importance of these influencing factors. Another reason for calculating with both subsidies and no-subsidies is to examine the cognitive bias of the reference dependence.

TABLE 4.12 The average investment costs for different types of energy-saving measures and per cluster of households (Euro)-the energy modules 2012 and 2018

2012			2018		
Cluster	Insulation	Double-glazing	Cluster	Insulation	Double-glazing
cluster 1	1875	2750	cluster 5	2589	2061
cluster 2	1250	1200	cluster 6	2277	2670
cluster 3	1950	3500	cluster 7	1300	2000
cluster 4	2500	2267	cluster 8	2358	3111

4.5.3 Expected utility theory (EUT) and cumulative prospect theory (CPT)

This study aims to estimate the input parameters of the EUT and CPT models to more accurately predict individual energy efficiency investment decisions. First, the initial input parameters are applied following previous studies [183, 258, 371, 451]. The EUT and CPT parameters are calculated using the equations (1–10) and (11–17), respectively. The initial values are presented in table 4.13.

TABLE 4.13 Initial values for input parameters.

Input parameters	θ	α	β	γ	δ	λ
Values	1.26	0.88	0.88	0.61	0.69	2.25

The EUT and CPT parameters are calculated for 2,779 and 2,878 homeowners of the two datasets using the initial parameter values. The results show that the CPT predicts the decisions of 86% of homeowners correctly. However, the EUT overestimates decisions and shows a positive value for 1441 homeowners who did not invest in any type of energy-saving measure. In the following subsections, the parameters of EUT and CPT per each cluster are identified. The differences between the predicted and actual percentages of households that made energy retrofits are minimised to estimate these parameters.

4.5.4 Identification of the parameters of expected utility theory (EUT) and cumulative prospect theory (CPT)

Genetic algorithm is used to estimate EUT and CPT parameters. The goal of this optimisation is to minimise the deviation between the retrofit rate estimated by EUT and CPT and actual retrofit rate obtained from the data set by changing the parameters. Estimating the values of all these parameters necessitates high computational times resulting from the complexity and non-linearity of the CPT parameters as well as the need to calculate 50 different energy price scenarios. The values of β, θ, γ, δ, and λ are calculated. To reduce the computational times, boundaries are defined for these parameters. The possible range for different parameters were identified using trial and error to narrow down the domain space. The maximum number of generations is constrained as well. An initial population of 100 with 10 generations appear to be sufficient to achieve sufficient results. increasing the number of generation above 10 and population size about 100 resulted in minimal improvement in the goodness of the objective function, therefore, these values are selected. The optimisations are conducted for four clusters of households and two types of energy-saving measures, i.e. insulation and double-glazing. The percentage of households that made positive decisions to conduct energy-saving measures is the indicator in estimating the parameters for each cluster and per type of energy-saving measure. Two reference points (RPs) are used to estimate the parameters and to examine the reference dependency of preferences proposed by Tversky and Kahneman [451] $(NPV = I_0 + \sum_{n=0}^{T} \frac{CF_t}{(1+r)^t} + RP)$ Following this formula, the investment costs can be decreased or increased to include different reference points. Here, the investment costs with subsidies and without subsidies are included to evaluate the cognitive bias of reference dependence. The subsidy data is collected from the Milieu Centraal website. Tables 4.14 and 4.15 show the optimisation parameters for EUT and CPT models using the energy modules 2012 and 2018.

TABLE 4.14 Cluster-level CPT estimates and Mean Error using the energy module 2012.

Reference	CPT												EUT	
	Subsidies						No_subsidies						Subsidies	
	β	γ	δ	λ	θ	dev	β	γ	δ	λ	θ	dev	θ	dev
Insulation														
cluster 1	0.33	0.71	0.71	1.37	9.94	0	0.24	0.92	0.07	1.81	3.53	2.48	1.84	21.43
cluster 2	0.68	0.11	0.05	4.85	7.28	4.23	0.21	0.45	0.46	6.35	0.32	2.08	26.59	3.28
cluster 3	0.28	0.34	0.41	2.86	8.16	12.46	1.31	0.87	0.56	8.77	8.56	6.1	2.50	32.13
cluster 4	1.11	0.01	0.31	0.52	7.82	9.19	0.76	0.78	0.03	7.12	9.42	3.67	2.48	37.80
Double-glazing														
cluster 1	0.26	0.57	0.39	4.45	0.78	0.29	0.53	0.93	0.24	3.22	0.02	10.43	0.78	5.79
cluster 2	0.03	0.31	0.71	2.26	1.60	0.43	0.06	0.54	0.24	7.05	0.21	3.00	2.49	17.17
cluster 3	0.86	0.10	0.48	3.76	0.14	0.61	0.04	0.44	0.41	6.91	0.65	0.61	3.08	19.94
cluster 4	0.30	0.55	0.91	6.44	1.33	1.07	0.38	0.53	0.02	7.61	7.54	4.64	3.06	21.35

TABLE 4.15 Cluster-level CPT estimates and Mean Error using the energy module 2018.

	CPT												EUT	
	Subsidies						No_subsidies						Subsidies	
	β	γ	δ	λ	θ	dev	β	γ	δ	λ	θ	dev	θ	dev
Insulation														
cluster 5	1.53	0.60	0.83	0.29	1.12	0.0	0.36	0.35	0.14	7.26	0.31	0.93	0.62	21.49
cluster 6	1.03	0.98	0.61	5.16	0.35	1.78	0.91	0.68	0.03	7.55	6.05	0.25	1.02	16.01
cluster 7	1.40	0.85	0.03	3.35	0.91	0.33	0.02	0.94	0.06	4.29	7.11	6.62	1.90	3.64
cluster 8	0.76	0.77	0.18	3.27	3.51	2.68	0.41	0.95	0.47	4.13	0.28	0	0.42	28.69
Double-glazing														
cluster 5	1.14	0.96	0.70	4.62	0.35	1.78	0.05	0.91	0.45	6.24	0.63	1.78	1.37	16.11
cluster 6	0.11	0.51	0.67	9.54	0.70	0.24	0.20	0.45	0.23	5.73	0.21	9.11	0.79	8.87
cluster 7	0.37	0.64	0.43	0.65	0.30	1.97	0.37	0.71	0.21	4.28	0.25	7.57	1.89	3.29
cluster 8	0.01	0.71	0.52	2.34	6.45	0.56	0.64	0.83	0.06	4.20	8.41	0.28	1.32	22.35

Comparing the expected utility theory (EUT) and cumulative prospect theory parameters (CPT) and overall results of CPT parameters

As mentioned, the EUT has a utility function that includes the wealth level and shows the constant relative risk aversion (CRRA) for each individual. The values of CRRA (i.e. θ) are calculated using the genetic algorithm method. The objective function is similar to CPT. Therefore, the differences between the actual percentages and the predicted ones are minimised. Based on the results and similar to previous studies [139, 183, 371, 451], CPT captures the actual behaviours reasonably well for the majority of the clusters, for two energy-saving measures, as well as, two reference points with and without subsidies. As mentioned by Rieger, et al., [371], the CPT's more accurate parameters are not solely due to the fact that CPT contains a large number of parameters. The main reason for better performance of CPT in comparison with EUT in predicting the rate of retrofit is due to inclusion of reflection effect and probability weighting. The reflection effect is another term for risk-seeking behaviour for loss and risk-averse behaviour for gain. Probability weighting refers to the fact that the demand of high gain to repay loss with equal chances cannot be described by a reasonable degree of risk aversion in the EUT model [367].
Evaluating the parameters of CPT determines several interesting results for the overall clusters as shown in table 4.16:

TABLE 4.16 Overall interpretation of CPT parameters.

Parameters	Interpretations
γ,δ,λ,θ	Changing the reference point has a statistically significantly influence on the coefficient values of γ and δ. No-significance impacts are identified for the coefficients of λ,θ (t-test, P ≤0).
β	The parameter β (i.e. 0 < β ≤1) shows the convexity of the value functions in 81% of CPT parameter estimations. This indicates the risk-seeking behaviours for loss on energy efficiency investments.
θ	The parameter of θ (i.e. ≥0) indicates the concavity of the value functions in all cases. Namely, it shows the risk-averse behaviours of individuals in gain regarding energy efficiency investments.
β,θ	The average β (0.52) is smaller than θ (3.25). The differences between these two parameters are statistically significant. Therefore, asymmetric value functions in gain and loss are identified. It means that in loss, the risk-seeking behaviour increase considerably with more losses. However, the rate of risk-aversion behaviour does not increase considerably with more gains from energy efficiency investments (Fig. 4.5).
γ and δ	Studies in decision making indicate that decision-makers do not weight rare events according to their actual probability chances of happening. Instead, small probability events are inclined to be overweighted for two reasons: (1) decision-makers may overestimate the chance that rare events happen; and (2) small probabilities are overweighted in terms of their impact on decisions. Considering these two reasons, rare events are given greater psychological weight in our minds than actual weight [68, 451]. The obtained values for γ and δ are between 0 and 1. Based on these values, the overweighting of small probabilities is confirmed for both gain and loss.
λ	The estimated values for λ for almost all and except for two cases are greater than 1. This indicates that the majority of homeowners consider losses more important compared to gains. For instance, the maximum value of λ is equal to 9.54. Therefore, on average, the individuals of this cluster perceive losses almost 10 times more important than gains.
Reflection principle	The results of the CPT parameters are tested by the reflection principle. Reflection principle means that there should be no correlations between the estimated parameters of CPT modelas stated by Kahneman [228]. The bi-variate correlations of the five CPT parameters are tested using the Pearson correlation and Superman's rho tests. The results show that no-significant correlations are identified. Therefore, the interpretation of coefficients using the CPT model is not influenced, and these coefficients can be interpreted independently.

Next, the parameters of CPT models are interpreted per cluster and per type of energy-saving measure, i.e. insulation and double-glazing, using the energy modules 2012 and 2018.

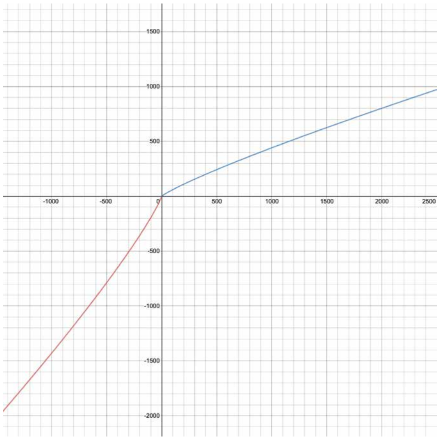


FIG. 4.5 the value function of CPT for cluster 3, installation of double-glazing, and the investment costs with subsidies

Results of the CPT's parameters for each cluster using the Netherlands Household Survey Energy module 2012

The parameters of different clusters using the energy module 2012 are explained in the following:

Insulation—subsidies

Cluster 2 shows high risk-seeking behaviour (β=0.68) of this group in losses compared to other clusters (similar to the proposed parameter value by Tversky and Kahneman [451]). Furthermore, the loss-aversion parameter is the highest as well (λ=4.85). Therefore, the individuals in this cluster prefer to accept higher risk to prevent future losses or to gain in future compare with other clusters. this results in higher rate for implementation of energy retrofits in this cluster compared to others (Tables 4.7 and 4.8). The level of average incomes and house values are the highest, as well. In contrast, cluster 4 shows the least risk-seeking behaviour in losses for insulation (β=1.11). This group is the youngest with newly constructed buildings (average year of construction of 2004). Apparently, people with higher income and more expensive houses are more likely to invest in energy retrofits compared to the young and low income group.

Clusters 2 and 4 have the lowest values for the parameters γ and δ, respectively. Therefore, cluster 2 (δ=0.05) would be highly concerned regarding the low probability of losses. In contrast, cluster 4 (γ=0.01) is more concerned about the small probability of gains with the second-highest number of installation of insulation

(Tables 4.7 and 4.8). Clusters 2 and 4 overweight the small probability of losses and gains, respectively. Cluster 1 has the highest and equal values of the parameters γ=0.71 and δ=0.71. This group overweights the small probability of losses and gains less than other clusters and behaves consistently in the domain of losses and gains. Cluster 1 contains multi-family dwellings with less than two household members. This result indicates when multiple families are living in the same building they will probably make decisions collectively. Therefore, they will cancel out individual tendencies to overweight probability of losses or gains.

Double-glazing—subsidies

The parameters of the CPT model for cluster 3 are estimated similarly to the original parameter values (i.e. β=0.86 and θ=0.86) proposed by Kahneman and Tversky [230]. The individuals of this cluster are less risk averse in gains but risk seeking in losses for installation of double-glazing. In addition, cluster 3 has the lowest γ (=0.10) and mean error (0.14) compared to other clusters. This could be due to the fact that buildings in this cluster are mainly from the construction period of 1984 and households are about 61 year old. Therefore, most of the houses are lacking double glazing in the original construction and as elderly people have a preference for higher indoor temperatures they are likely to install double glazing. Cluster 4 has the highest loss-aversion coefficient for the installation of double-glazing (low number of double-glazing installations). Cluster 1 has the lowest δ (=0.39) for double-glazing, which means that this group would be highly concerned about the small probability of losses. This cluster also has the lowest number of installations of double-glazing compared to other groups.

Insulation—no-subsidies

The reference point is changed in the NPV formula by including the investment costs of insulation without subsidies. Different values for five parameters of CPT are identified. In this new optimisation, the lowest mean error is calculated for cluster 2, similar to the RP with subsidies. The inclusion of subsidies makes the proposed optimisation model more realistic as subsidies could have significant effect in decision towards implementation of energy efficiency measures. As excepted inclusion of subsidies in the reference point improved the goodness of the objective function 50% in almost all cases. The highest values of β equal to 1.31 and 0.76 are calculated for clusters 3 and 4. Therefore, these two groups are risk seeking in the domain of losses for insulation. For these two groups, the values of loss aversion parameters are the highest, as well. Namely, clusters 3 and 4 consider losses more than 8.77 and 7.12 as important as gains.

Double-glazing—no-subsidies

Compared to the insulation, the mean errors are increased when the RP includes the investment costs without subsidies. In addition, three θs (out of four) are $0 \leq \theta \leq 1$. This range of θ makes the value functions of CPT more comparable to the one proposed by Kahneman and Tversky [230]. The results for the parameter γ are not changed in terms of interpretation. However, the order of magnitude has increased.

Results of CPT's parameters for each cluster using the energy module 2018

The results of CPT parameters for different clusters are explained using the Netherlands National Household Survey Energy module 2018.

Insulation—subsidies

The mean errors are smaller using the energy module 2018. The parameter β shows risk-seeking behaviour and risk aversion in gains. For all clusters, the θ follows the original curvature proposed by Kahneman and Tversky [230]. By comparing the parameter β, cluster 8 has the lowest β_8=0.76. This indicates the highest risk-seeking behaviours of cluster 8 in losses for insulation compared to other clusters. Cluster 6 has the second-lowest value for parameter β. In terms of dwelling and household characteristics, cluster 8 has the highest number of installed insulation, highest average income, and average house values compared to the other clusters. Furthermore, cluster 6 ranks second for all these attributes. Furthermore, cluster 6 has the lowest value for θ, which means this group has the least risk aversion to gains. Considering the household characteristics (Table 4.10), cluster 6 has the youngest average compared to other clusters. Regarding the parameter γ, the value of this parameter for cluster 6 is the highest. Therefore, this group would be less concerned about the small probability of gains for insulation. At the same time, the loss-aversion coefficient (λ=5.16) is the highest compared to other clusters. Furthermore, cluster 6 also has the lowest value of θ. Hence, this group is the lowest risk-averse in gains. Based on tables 4.9 and 4.10, cluster 6 ranks second in terms of insulation, average income, and house value compared to other clusters. Clusters 7 and 8 have the lowest δ_7=0.03 and δ_8=0.18, respectively. Therefore, these groups would be highly concerned about the small probability of losses.

Double-glazing—subsidies

For both datasets, double-glazing with investment costs including subsidies has the lowest mean error compared to other combinations of investment costs with no subsidies. Regarding the parameter results, clusters 6, 7, and 8 are risk-seeking in preventing losses. Based on the values of θ, clusters 5, 6, and 7 confirm the curvature proposed by Kahneman and Tversky [230]. Among these clusters, cluster 7 with $\theta = 0.30$ is less risk-averse in gains. This cluster belongs to multi-family dwellings with the highest probability of relocation over the last two years compared to other clusters. The highest value of parameter λ is equal to 9.54, which implies that individuals of cluster 6 perceive losses to be more than 9 times as important as gains. Based on table 4.9, this group's number of double-glazing installations (=247) is the highest compared to other clusters. Regarding the probability weighting function parameters, cluster 5 has the highest values of γ=0.96 and δ=0.70, which indicates that these individuals are less concerned about the small probability of losses and gains from double-glazing installation. This cluster has the lowest number of double-glazing installations in the past 5 years (Table 4.9).

Insulation-no—subsidies

The mean errors of clusters 5,6, and 8 are declined when the reference point is set to the investment costs without subsidies. In this case, cluster 6 and 5 have the highest loss aversion parameters of λ=7.55 and λ=7.26 compared to other clusters, respectively. The values of θ for clusters 5 and 8 are equal to 0.31 and 0.28, respectively. This implies that these groups tend to be risk averse in the gains for installation of insulation. Cluster 6 has the highest β=0.91 and λ=7.55 values, which indicates less risk seeking in losses and high loss aversion in insulation installation. Based on Table 4.10, this cluster ranks second in insulation installation. The highest values of parameter γ are identified for clusters 7 and 8 (0.94 and 0.95, respectively). In addition to this, cluster 8 has the highest values of δ, which indicates these people would be less concerned about the small probability of losses. This high-income group of households has the highest rate of installed insulation in the past five years (table 4.9).

Double-glazing—no-subsidies

Similar to the results using the energy module 2012, the mean errors are increased for clusters 6 and 7 compared to the previous RP. Again, the values of the parameter θ of cluster 5, 6, and 7 are $0 \leq \theta \leq 1$, which confirm the proposed shape of value functions by Kahneman and Tversky [230]. The parameter values of β for all clusters conform to the proposed convexity as well (risk-seeking for loss). Cluster 8 has the lowest parameter value of δ=0.06, which implies this group would be highly concerned about small probabilities of loss. Based on table 4.10, this group has the highest average income, highest average house value, and the second most installations of double-glazing.

4.6 Discussion

This study has applied quantitative methods to examine the impacts of cognitive biases on energy efficiency investment decisions. It has compared expected utility theory (EUT) and cumulative prospect theory (CPT) and evaluating their potential to predict and explain decision-makers' behaviours. EUT assumes rational decision-making under risk, an assumption CPT disputes by explaining actual behaviours. According to CPT, decision-makers display different cognitive biases: reference dependency, loss aversion, diminishing sensitivity, and probability weighting. These agents generally behave asymmetrically, to their loss and gain.

4.6.1 Comparing the performance of expected utility theory (EUT) and cumulative prospect theory (CPT) in predicting the decision-makers behaviours

This study has demonstrated CPT's superiority in explaining renovators' decision-making behaviours. EUT is useful in a minority of cases, but CPT can predict these cases as well [94, 139, 371], while also providing deeper insights into qualitative and quantitative studies on energy efficiency [147, 165, 170, 183, 481]. CPT's explanatory strength derives from its consideration of cognitive biases, such as the reflection/framing effect (i.e. risk-seeking in loss and risk aversion in gain), probability weighting (over/underweighting small/average probabilities), and loss aversion [94, 183, 371]. The evidence of CPT's superiority is as follows:

1. Using the initial parameters from previous research [183, 258], EUT overestimated the actual decisions of approximately 50% of homeowners. However, CPT predicted the decisions of 86% of individual homeowners accurately.

2 CPT determined homeowners' risk-seeking behaviours for losses for 81% of the total number of groups. Furthermore, homeowners' risk-averse behaviours of homeowners were identified for all cases, confirming the function proposed by Tversky and Kahneman [451]. Furthermore, CPT verified over-weighting of small probabilities based on estimations for the corresponding parameters (i.e. γ and δ). For the majority of the groups, the loss aversion factors were considerably greater than those proposed by Tversky and Kahneman [451].

3 CPT's mean errors were in many cases smaller than EUT's.

Cognitive bias of reference dependence

Modifying the reference points significantly influences the parameter values of γ and δ. Therefore, the results of this study are somewhat similar to the quantitative study by Hackel, Pfosser, and Trankler [183], which found the determination of a reference point to be very important. Reference dependence's importance is stated in previous qualitative studies on energy efficiency (e.g. [147, 165, 481]). For cases involving insulation, using the reference point of no-subsidies slightly improved CPT's results. The reverse was identified for cases involving double-glazing; namely, the reference point including subsidies resulted in closer predictions of homeowners' actual behaviours. The conclusions were the same using both datasets.

4.6.2 Identifying and comparing cognitive biases for different groups regarding the installation of insulation and double-glazing

This study mainly contributes to extant knowledge by empirically examining CPT's parameters for each group of homeowners. The cognitive biases of reference dependency, loss aversion, diminishing sensitivity, and probability weighting were quantified for four clusters of homeowners, using household and building characteristics, as well as the probability of relocation in the past two years. The energy retrofits of insulation and double-glazing were also investigated. Rieger, Wang, and Hens [371] estimated the CPT parameters for different groups using an international survey of 53 countries. The author investigated the risk preferences of a large number of undergraduate students, as shown through hypothetical choices in a predefined set of lotteries. This is the first study in the field of energy efficiency that empirically investigates CPT parameters for clusters of homeowners.

Table 4.17 presents the main findings of this study. The main clusters' highlights are illustrated for different types of energy saving measures, using different reference points using the energy modules 2012 and 2018. Based on the investigation of CPT parameters, the study identified the importance of risk-seeking in loss, concern about small probabilities and loss aversion factors:

1 For insulation, the households that invested more in installing insulation were also more risk-seeking in loss[15] and highly concerned about the small probabilities of loss and gain, as well as being highly loss-averse. These households often had the highest average income and house values. For cluster 4 of energy module 2012, this group was the youngest and had the highest probability of relocation. The results remained the same upon modifying the reference point. In this case, the groups of people who invested more were extremely loss-averse as well.

2 For double-glazing, the highly loss-averse people had invested more in double-glazing than other groups. For cluster 8 of energy module 2018, homeowners who invested the highest amount in double-glazing were risk-seekers in loss and highly concerned about the small probabilities of loss. These groups always had high house values and were often the highest average income group. For instance, cluster 3 had the second highest house values. However, in terms of income, they were ranked third.

15 If the risk-taking person is offered two choices: either lose 50 euros as a sure thing or have a 50% chance of losing 100 euros. A risk-seeking person with losses will choose the second option.

TABLE 4.17 Identifying and comparing CPT's parameters among different clusters and energy saving measures (i.e. Insulation and Double-glazing).

	2012		2018	
	CPT parameters	household and building characteristics	CPT parameters	household and building characteristics
insulation-subsidies	Cluster 2 and 4: (1) highest values for the β, i.e. the highest value for risk-seeking behaviour in loss, (2) lowest values for γ and δ, i.e. highly concerned about small probabilities of loss and gain - cluster 2: has the highest loss aversion parameter = 4.85	Highest number of installed insulation, single-family, highest number of rooms highest average income and highest average house value cluster 4: higher probability of relocation in the past 2 years	cluster 8: (1) highest value of 0 ≤β ≤1 pro-posed by Tversky and Kahneman [451], other clusters have β values more than 1. (2) the lowest δ, i.e. highly con-cerned about small prob-abilities of loss cluster 6: highest loss aversion parameter = 5.16, high-est value of γ, i.e., least risk aversion in gain	the highest number of installed insulation, high-est income and house values single-family highest number of room average construction year: 1970s
double-glazing-subsidies	Cluster 3: (1) highest value of β, i.e. highest values for risk-seeking behaviour, (2) the lowest value for γ, i.e. highly concerned about small probabilities of gain			
	Second ranking of installed double-glazing, second-ranking of house value average construc-tion-year: 1984	cluster 6: highest loss aversion parame-ter = 9.54	the highest number of installed double-glazing, highest income and house values	
	Cluster 1: the highest value of γ, not highly concerned about small probabilities of gain	the lowest ranking of installed double-glazing	cluster 3: lowest loss aversion parameter	the lowest number of installed double-glazing, highest income and house values
insulation-no subsidies	- cluster 2: (1) high loss aversion = 6.35, (2) the value of γ is less than δ, which is exactly following the pattern proposed by Tversky and Kahneman [451]. clus-ter 2 concerned more about the small proba-bilities of loss compared to gain. - cluster 4: results remain the same: (1) highest 0 ≤β≤1, i.e. risk-seeking behaviour in loss, (2) high loss aversion = 7.12.	- highest number of installed insulation, income and house value - second highest number of installed insulation, income, and house value	cluster 6: results remain the same: (1) highest β, i.e. risk seeking be-haviour in loss, (2) high-est loss aversion = 7.55	the second-highest number of installed insulation, income, and house value

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TABLE 4.17 Identifying and comparing CPT's parameters among different clusters and energy saving measures (i.e. Insulation and Double-glazing).

	2012		2018	
	CPT parameters	household and building characteristics	CPT parameters	household and building characteristics
double-glazing-no subsidies	cluster 2 and 3: (1) high loss aversion parameters (7.05 and 6.91, respectively), cluster 3: (2) more risk-averse in gain	cluster 2 and 3: first and second-ranking of the number of installed double-glazing cluster 2: highest income, house value cluster 3: highest house value	cluster 8: (1) highest value of 0<β<1 proposed by Tversky and Kahneman [451]. (2) lowest δ, i.e. highly concerned about small probabilities of loss cluster 6: (1) highest loss aversion parameter = 5.73, (2) lowest value of δ=0.23, i.e. highly concerned about small probabilities of losses	the highest number of installed double- glazing, highest income and house values

4.6.3 Insights for behavioural interventions using the identified cognitive biases

This study did not evaluate the impact of behavioural intervention. However, based on the results, potential behavioural interventions can be identified. Table 4.17 presents the cognitive biases in energy retrofit decisions regarding insulation and double-glazing for homeowners. Using this table and the results of sections 4.6.1. and 4.6.2., the identified cognitive biases and potential behavioural interventions can be proposed as presented in table 4.18.

TABLE 4.18 Behavioural interventions using the identified cognitive biases.

Cognitive bias	Behavioural interventions
Loss aversion	The loss-averse people were recognised in different clusters. Furthermore, the groups of homeowners with the most installed energy saving measures were often risk seekers in loss. For these people who are highly loss-averse, highlighting the cost/loss reductions from using energy retrofits can be more effective than emphasising the benefits of energy saving measures, as also mentioned by Frederiks et al. [147].
Risk averse in gain	The majority of homeowners were risk-averse in gain. That is, they would rather engage in a risky behaviour to avoid certain loss than to engage in a similarly risky behaviour to obtain a comparable gain [451]. Promoting low-risk and secure energy retrofit might be more persuasive for risk-averse homeowners [147].
Social influence	Multi-family dwellings often invest less compared to single-family dwellings. This might be due to barriers preventing an agreement among the homeowners for conducting energy retrofits. This group can be motivated by other people's attitudes; for instance, a trusted, well-informed neighbour can explain the benefits of energy efficiency retrofits to other neighbours successfully. Furthermore, formulating energy retrofits as a socially desirable behaviour can increase the probability of other people conducting retrofits. The importance of these behavioural interventions are specified by [140, 147].

4.7 Conclusion and policy implications

The current study contributes to the identification of cognitive biases in energy retrofits by developing a theoretical framework and conducting empirical analyses of homeowners' retrofit decisions in the Netherlands. From the theoretical perspective, models and approaches incorporating specific cognitive biases have been presented, including prospect theory as proposed by Tversky and Kahneman [451] (considering the cognitive biases of isolation effect, certainty effect, endowment effect, and reflection effect); and the theory of moral sentiments proposed by Smith [410] (social norm, social approval and status). The study has also reviewed current studies on cognitive biases to identify the main known cognitive biases in the field of energy efficiency. The identified cognitive biases include status quo bias/default setting, loss aversion, risk aversion, availability bias, and sunk cost fallacy.

This study compared expected utility theory (EUT), which assumes a rational decision-maker, to cumulative prospect theory (CPT), which assumes the influence of risk and uncertainty, when studying homeowners' retrofit decisions. EUT as developed by Von Neumann and Morgenstern [467] and CPT as proposed by Tversky and Kahneman [451] were presented. For the empirical application, CPT was applied for investigating cognitive biases in homeowners' energy retrofits. These cognitive biases included: (a) reference dependence/status quo bias/default setting (b) diminishing sensitivity/reflection effect/framing effect/certainty effect (i.e. different behaviours for gains vs. losses), (c) loss aversion, and (d) probability weighting. Furthermore, the cognitive biases were investigated for four homogeneous groups of individuals, as well as two types of energy retrofits, i.e. insulation and double-glazing. The differences and similarities of cognitive biases for different groups were then evaluated. Finally, potential behavioural interventions for each cluster of individuals biases were proposed.

Overall, there is evidence of reference dependency, reflection effect, loss aversion, and probability weighting. CPT was considerably better than EUT at predicting the energy efficiency decision behaviours for four clusters and two types of energy retrofits (insulation and double-glazing). Furthermore, changing the reference points significantly influenced the parameter values of the probability weighting function (i.e. γ and δ). This indicates the importance of status quo bias in individuals' decision-making. For the reflection effect, individuals' risk-seeking in losses and risk aversion in gains were also identified as significant. Furthermore, diminishing sensitivity in losses was less compared to gains, since the average of β (for negative outcomes) was less than θ (for positive outcomes). Based on CPT, people overweigh the small probability of both gains and losses. For this purpose, the corresponding parameters of CPT were $0 < \gamma,\delta \leq 1$. These ranges of parameter values were estimated for four clusters of individuals. Finally, people prevented losses significantly. The maximum loss aversion parameter is equal to 9.54 for energy saving investment, which is almost 5 times more than the estimated value by Tversky and Kahneman [451].

The groups with highest average income and house values in the National Household Surveys of 2012 and 2018 showed highest risk-seeking parameter for losses. These groups installed the highest number of insulation and overweighted the small probabilities of losses. In data for both years, the youngest group of individuals were among the least risk-averse in gains. However, the correlation between age and installation of insulation is not clear. The average income and house values are significantly more important in determining the decision towards installing insulation. For double-glazing, similar conclusions could be drawn using the 2012 and 2018 datasets (cluster 3 of 2012, cluster 6 of 2018). The risk-seeker individuals for losses, who also overweighted the small probabilities of losses/gains more than other groups, installed more double-glazing compared to other groups (second-ranking). In 2018 dataset, the cluster with the lowest amount of installed double-glazing, showed less risk-seeking behaviours in losses. Similar conclusions are achieved for the reference point no-subsidies. Our findings show that cost/loss reductions for installing energy retrofits can be more effective, compared to promoting energy retrofits by their advantages and benefits.

5 Transaction cost barriers

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Note: In Chapter 2, the importance of the behavioural factors and transaction cost barriers were illustrated in conducting the energy efficiency renovations. A more in-depth analyses is essential to clarify which factors determine the transaction costs during the renovation processes. First, this chapter focuses on understanding the determinants of the transaction cost barriers. A theoretical framework is developed that categorised the determinants into transactor and transaction characteristics, and institutional aspects. Second, the transaction costs are explored from different perspectives of suppliers, public authorities, and homeowners to have a comprehensive view of stakeholders transaction cost barriers. In addition, based on the first study, the energy efficiency renovation is mainly conducted with other types of renovations. Therefore, the impacts of transaction cost barriers are compared for renovation (categorised into exterior and interior types) and energy efficiency renovations. Also, the main sources of information, such as maintenance companies are evaluated for different types of renovations. The data is collected from a survey of 3,776 homeowners in the Netherlands.

ABSTRACT

The renovation of housing stock in the Netherlands has the potential to help achieving the country's climate change targets. However, there are non-monetary transaction cost (TC) factors, such as searching for information and finding a reliable professional/contractor, that present barriers to householders when making the decision to renovate or not. This study evaluates the impact of the transaction costs on the renovation decision-making process for two groups of householders, current renovators and potential renovators, and for three types of renovations, exterior renovations, interior renovations, and energy efficiency renovations. The study analyses householder renovation decisions in relation to TC barriers based on information gathered at different stages of the renovation processes. The data was collected from a survey of 3,776 homeowners in the Netherlands. The main identified TC barriers were found to be at the consideration, decision, and execution phases of the renovation decision-making process, and are: finding a reliable professional/contractor to do exterior renovations, determining costs for interior renovations, and finding ways to increase the energy efficiency of the house using energy-saving

renovations. The main sources of information for householders are construction stores/Do It Yourself (DIY), installations and maintenance companies for exterior and energy efficiency renovations, while for interior renovations it is construction stores/DIY companies, Internet, and recommendations from family/friends. The findings from this study contribute to more effective management and distribution of both information and financial resources in relation to the renovation of housing stock.

KEYWORDS Renovation; Energy Efficiency Renovation; Homeowner; Decision-making; Transaction Cost (TC); Information barrier; the Netherlands

5.1 Introduction

The Netherlands's built environment is undergoing a major renovation due to the country's climate agreement that came into effect at the end of 2018. Under this agreement, the housing stock and other types of buildings that are currently moderately insulated and almost all heated by natural gas, are required to transform to well-insulated buildings using sustainable heating systems with clean or self-generated electricity [133]. However, a recent report by the Netherlands Environmental Assessment Agency (PBL) reveals that achieving the CO_2 emissions and energy efficiency targets set by the agreement are impossible by the horizon of 2020. Regarding the housing sector, the estimated energy consumption and CO_2 emissions are higher than the numbers predicted by the National Energy Outlook in 2017, and data shows that natural gas consumption by households barely decreased between 2015 and 2017 [331].

The owner-occupied sector had about 70% of the housing stock in 2017 [131]. Therefore, energy renovations in this sector can contribute significantly to reaching the energy targets. Despite the great potential of the owner-occupied sector in reducing energy consumption, much less strict targets are designed for this sector compared to social housing rental sector. For example, energy saving for the owner-occupied and rental sectors were set to be 3 and 7 petajoules respectively in the 2013 energy agreement. However, the estimated energy savings of these sectors is predicted to be 3 and 2 petajoules respectively by 2020 [331], which means that by achieving 100% of the energy saving target the owner-occupied sector will have contributed 1.5 times more to energy saving than the social housing sector that only achieved 28% of its target. Notwithstanding these results, managing renovations in the owner-occupied sector is more difficult compared to other housing sectors because individual homeowners are responsible for renovating their own houses, whereas in the social housing sector there is a central organisation to manage energy efficiency renovations.

Homeowners usually need to follow different phases in a renovation process. The phases are: consideration, planning, decision making, implementing, and experiencing [376, 480]. Transaction costs (TCs) are non-monetary costs associated with different phases of the renovation process for homeowners. TCs are regarded as one of the main barriers in achieving energy efficiency targets. These costs have different forms such as time, effort, complexities in doing renovations, hassle factors, mess and nuisance, and uncertainties. TCs are inevitable and usually unpredictable. For example, in the consideration phase, renovators need to compare different types of energy efficiency measures to find the most appropriate measure in terms of cost and quality. This might prolong the duration of the renovation process and add significant extra effort [480, 481]. Also, imperfect information may impede investment from actors in the market and therefore reduce the benefits of using more appropriate energy efficiency measures [239, 313, 316].

Despite the importance of TCs in achieving energy targets, only a few studies have investigated householder TCs [48, 190, 480]. Neglecting TCs in assessing and preparing energy efficiency policies causes sub-optimal decision and allocation of resources [453]. This paper therefore investigates transaction cost (TC) factors at different stages of the renovation process from the householders' perspective to evaluate the importance of these factors on renovation decisions. A survey was conducted among 3,776 homeowners to collect the data, which were quantitatively analysed to determine the importance of the TC factors. Two groups of householders, renovators and potential renovators, are studied to evaluate the effects of TCs at different stages of the renovation process. Renovators have experienced the renovations and can evaluate the barriers during the implementation phase. Potential renovators are in the consideration phase, they are willing and planning to renovate and can evaluate the barriers associated with this phase; targeting this group of householders can accelerate the renovation rates in the owner-occupied sector. Influencing factors are compared for the different types of renovations (categorised into exterior and interior renovations) and energy efficiency renovations [56, 69, 350, 359]. The importance of different sources of information is examined. The results can be used to accelerate the rate of energy renovation by identifying the main TC factors to be targeted by policy interventions.

This paper is organised as follows. In section 2, the recent literature on TCs regarding the decision making and renovation process are reviewed. In section 3, the research methodology is described, the database is explained, and statistical and logistic regression analysis are provided. The results of the analyses, discussion on these results, and conclusions are presented in sections 4, 5, and 6, respectively.

5.2 State-of-the-art

5.2.1 Renovation and energy efficiency renovation

In general, the term renovation represents interventions with no energy-saving objective. Energy efficiency renovations on the other hand lead to energy saving, energy efficiency and/or micro-generation of electricity or heat. In this section, literature considering both renovations and energy efficiency renovations are reviewed [56, 69, 350, 359].

Pardalis et al. [350] investigated the influencing factors of homeowner renovations for detached houses in Sweden. The renovations were categorised into energy efficiency renovations and aesthetic renovations. The results show the importance of socio-economic variables on householders' energy efficiency renovations. While emphasising the role of one-stop-shop for facilitating energy efficiency renovations, no significant influence of financial incentives were found for the application of the one-stop-shop. Pomianowski, et al., [359] proposed a tailor-made renovation packages for individual family homeowners in Denmark. The main motivations of householders for renovation were improving comfort, repairing deteriorated elements of the house, or doing aesthetic renovation. Most of the time, energy saving is not the main driver of renovation. Therefore, providing a package of renovations that considers both the interests of householders and energy saving measures is essential. In this approach, the most cost-effective renovation package was selected, while the investment cost is comparable with the available budget. A similar study was carried out among Swedish homeowners, where it was found that the rate of renovation is related to the demographic characteristics and construction period of the building [56].

The influencing factors of energy-related refurbishment for German homeowners was investigated by Baumhof et al. [39]. It was concluded that consultations and information sharing at one-stop-shops can increase the rate of energy efficiency renovations. Similar to the aforementioned studies, enhancing the appearance of the house, improving comfort, reducing structural damage, and increasing the house value, were considered as the main motivations for renovation. Among the barriers, complexities in carrying out the renovation, finding a reliable professional/contractor, and not enough time for planning and conducting renovations, were mentioned. In another study, Baumhof, et al., [38] demonstrated the impact of behavioural beliefs on the decision-making process for single family houses and multi-family houses. The public authorities can motivate homeowners by using incentives, such as showing the aesthetic appearance of renovated buildings and providing information.

The interactions between different characteristics such as specific type of houses and one specific group of householders or the interactions between different actors on renovation decisions were studied by Buser and Carlsson [69]. The aim was to explore the roles of the interactions of influencing factors on low percentages of energy efficiency renovations in the total renovation activities for the homeowners. Interviews, workshop, and participatory observation methods complemented with in depth analysis were used for 24 small craftsman firms, 8 houses, and homeowners. The identified hindrances were the discovery of unsuspected house characteristics, the complexity of choices and decisions to be made, and the associated financial costs. All these factors, i.e. the role of houses and the various attributed meanings and representations of the renovation process, need to be considered and recognised to achieve successful renovation for single-family households.

Renovations can be categorised into exterior and interior types of renovations, but few articles have evaluated specific interior or exterior types [223, 224, 225, 350, 443]. Joudi et al. [224] examined the importance of interior covering on the energy efficiency of buildings compared to previous literature that studied the impact of exterior covering and solar heat gain on energy consumption. Joudi et al. [224] analysed different scenarios with reflective coverings and found that reflective covers for the interior and exterior are more suitable for colder climates and warmer climates, respectively.

5.2.2 Transaction costs definition and the determinants

New institutional economics use TC theories to describe market behaviour that is mainly due to imperfect and asymmetric information. The process of organising and finalising the activities is investigated, especially the impacts of these activities on the performance of the projects and/or actors involved through transactions

TOC

with other actors in the market. There is no unique or standard way of defining TCs [323, 443]. This study uses the definition by Coase [80]; Ostertag [239]; Mundaca et al., [316]; Kiss [239] in which TC is defined as any indirect inevitable cost in a transaction that affects the consumer's decision (Coase 1960). TC is a sub-category of 'hidden costs' that is not adequately considered and consists of search for information, negotiating, and monitoring costs [313, 316, 345]. The key factors that influence the from and impact of TCs are classified as: 1) Transaction characteristics - degree of asset specificity, uncertainties surrounding transactions and frequencies; 2) Transactor characteristics - bounded rationality and past experiences, opportunism, trust and confidence of the shared information between parties; 3) Type of institutional environment - the formal and informal legal, social and political rules; and 4) Type of institutional arrangement - the ways of production, distribution, and consumption of goods and services [81, 453]. Three main elements of transaction characteristics are as follows: (1) Asset specificity - TC can be created whenever an asset is allocated for a specific purpose. In case of the renovation decision-making processes, the asset specificity is due to the investment in a specific type of technology/measure or specific skills/knowledge; (2) Uncertainty - any opportunistic behaviour or asymmetric information affect the confidence, trust, or certainty in making decision. In a renovation decision-making process, the two main types of uncertainties are expected benefits and opportunistic behaviour; and (3) Frequency - this element is related to uncertainty, since a householder with more experiences has less uncertainty over the outcomes of renovation [135]. See Figure 5.1.

Some of the TC studies focused only on one of the phases of decision-making process e.g., searching for information and exploration [79], TCs in implementation, controlling, and enforcing [475],while others considered all of the phases (overall activities) [151, 286]. The overall activity approach is followed in this study. The scale of TC is usually indicated as a proportion of total investment cost (%) 4, but sometimes in monetary terms or in work load, e.g. time [239]. We consider the time and efort for different activities in the renovation decision-making process as the main currency of TCs.

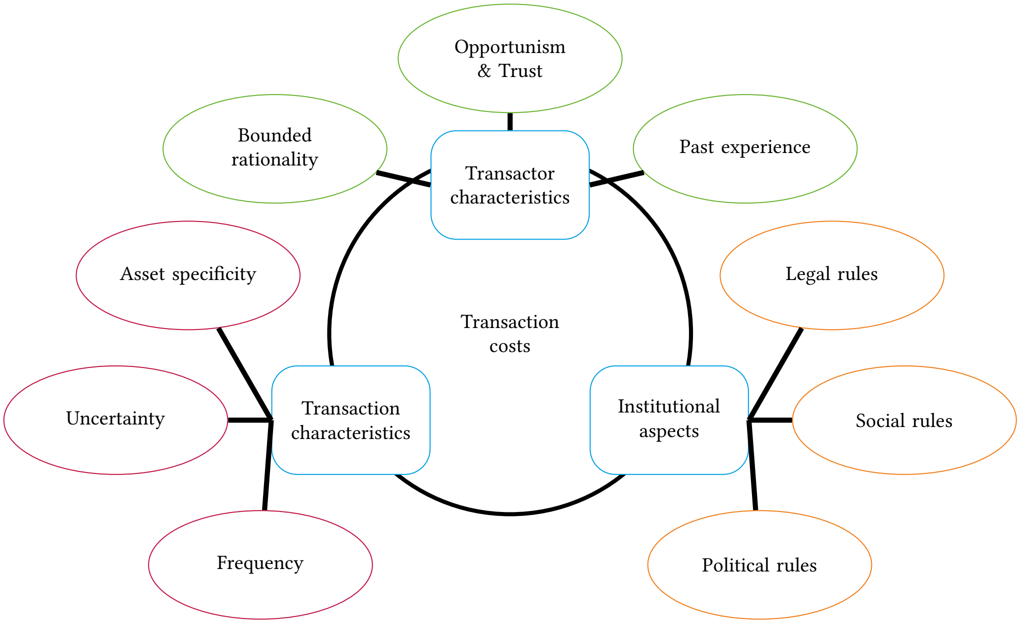

FIG. 5.1 The determinants of transaction costs

Supplier transaction costs

The cause and scale of TCs in supplier transactions were studied by Mundaca [314], who discovered that the parties involved found searching for information, advising consumers, and consulting with agents and contractors difficult to handle; the author quantified TCs for lighting and insulation, which were 10% and 30% of the total investment costs respectively. In another study, Mundaca et al. [316] focused on TCs for investors/project developers. They performed a literature review (meta analysis) and developed a taxonomy consisting of five different TCs: (1) search for information costs, (2) negotiation costs, (3) approval and certification costs, (4) monitoring and verification costs, and (5) trading costs. A list of factors in the implementation and operation of low-carbon technologies and scale of TCs was presented. Endogenous factors, such as size and complexity of the project, large number of intermediaries, and less experience increase the TCs. The investigation showed that the sources and estimates of TCs are specific to cases and circumstances.

Kiss [239] evaluated TCs from the building owner and developer perspective in the planning and implementation phases of a passive house-oriented renovation in Sweden. The TCs associated with passive houses are higher compared to conventional renovations due to the lack of experience that building owners and developers have of concepts and technologies. The most important TCs were associated with the project formulation, target setting, and the search for passive house technologies. Therefore, the major TCs are associated with the planning and implementation phases of renovations and illustrate the differences of TCs at different phases of a renovation. The study also indicated that TCs can be reduced by increasing knowledge over the renovations of passive houses.

Valentova, et al. [453] examined the role of actors on the scale and structure of the TCs of two major energy efficiency subsidy programmes in the Czech Republic. The impacts of experience and knowledge were found to be lower compared to the study by Kiss [239]. The results show that the share of TCs are lower for the bigger projects. For instance, TC share with 10,000 and 1,000,000 euros subsidies are 30% and 4%, respectively. However, the dependency between the actors and the TC scale could not be confirmed.

A TC framework from the real estate developer and architect's perspective was developed by Queena Qian and Chan [366] using a case study in Hong Kong. The aim was to study the reluctance of the market to invest in energy efficiency measures. The method of analysis was in depth interviews, the results of which highlighted the negative impact of TCs on building energy efficiency. Factors, such as split incentive, information asymmetry, opportunistic behaviour, and ill-informed users affect TCs and the stakeholders willingness to participate. In a study by Qian et al. [363], it was assumed that individual stakeholders steadfastly guard their interests in any given investment decision. The researchers investigated the extra TCs affecting the willingness of stakeholders to take part in green investments. The findings suggest that the decision of developers and end-users over investing in green buildings is complex process, where TCs play a major role. Minimising the TCs incurred in the complex decision-making process will not only benefit the stakeholders but also bring net regenerative outcomes to society.

Public authority transaction costs

Since TCs account for 8-38% of the total costs for public authorities, neglecting TCs in the evaluation (and preparation) of energy efficiency policies causes a sub-optimal allocation of resources [82, 453]. However, the TCs of a new energy efficiency policy can be influenced by the existing institutional environment and the

TCs would be reduced if the new policy and the existing environment are consistent with each other. The reason being that there would be less information collection, less legislative and administrative activities for controlling the current norms, less information distribution, and less monitoring and enforcement [82]. For instance, if the new policy affects private parties' rights, the public authorities endure high TCs for implementing the new policy [76]. Decentralisation of the governance structure and a trusting relationship between public authorities and private parties can reduce TCs due to less administrative activities [293].

The TCs of parties are interrelated. If public authorities invest in collecting information, analysing and distributing this information for free to other parties, the initial and ongoing TC for gathering information by private parties might reduce at the expense of public authorities. No statistically significant difference was found between total TCs of public entities and private companies who are involved in projects [453]. The optimum level of TCs can be achieved by centralising internal processes (especially in the preparatory phase and in public tenders) and by having transparent local and national laws.

Household transaction costs during renovation

Studies on householder TCs can be categorised as: (1) analysing the householder TCs for any activity in the dwelling (e.g., studying the impact of TCs on more people staying in a particular house) (Haurin and Gill [190]), (2) studying TCs related to renovation (e.g.,(Charlie Wilson, Crane, and Chryssochoidis [480])).

Bjorkqvist and Wene [48] estimated the TCs involved in changing a heating system as equal to 18 hours, which represented 13-28% of the predicted investment cost. They defined TCs as time spent at each decision stage. However, quantifying TCs has been criticised due to unclear time allocation for a specific activity. A study in California found that high implicit costs were incurred to collect information on the benefits of energy saving of different appliances, i.e. lighting and washing machine, for householders. Inadequacy of utilising and processing information are other hindrances to investing in energy efficiency technologies [392].

Imperfect information and TCs may lead to the selection of less energy efficient appliances by a householder compared to a well-informed social planner. Consumers must decide by evaluating the prices and expected future performance of appliances. Whether or not householders endure high costs and considerable effort to fulfil accurate and proper expectations, the scale of energy efficiency in the competitive market might be lower than socially efficient outcomes [202].

TOC

The uptake of energy saving measures is tenfold when monetary incentives are merged with information provisions [143]. In Norway, the owner-occupied sector has a major share of the housing stock. The successful Norwegian homeowners in doing energy efficiency renovations are the informed or the experienced ones. Lack of knowledge, lack of trust in advice from specialists, or preferences for doing the renovations by themselves, hinder energy efficiency renovations [376]. These studies indicate the importance of providing information to stimulate energy efficiency renovations.

In the following section, the main influencing factors in the renovation decision-making process are explained. Although the focus is on TC barriers, other important factors in householders' decision-making processes are included, such as socio-demographic variables and motivation for conducting renovations.

5.2.3 Different phases and the determinants in the decision-making process

A renovation consists of five different phases: consideration (understanding the needs, information search and pre-evaluating), planning, finalising the decision, executing, and experiencing (post-evaluating) [32]. In the following subsections, the determinants of TCs are discussed for each phase of the renovation process.

consideration

In the consideration phase, the critical influencing factors are socioeconomic factors, such as age, education, and income. Table 5.1 summarises the main socioeconomic variables and motivations in conducting renovations as identified by Ebrahimigharehbaghi, et al. [112].

TABLE 5.1 Socioeconomic factors and motivations in conducting renovations.

Categories	Factors
Socioeconomic examples	Age, Education, Income, Mover/ Stayer, Number of Occupants
Drivers	Cost saving, Increasing the house value, Increasing comfort, Repairing/ Replacing equipment

In this phase, householders need to find information on the type of renovations and appropriateness for their houses. Expectations on the cost and benefit of a renovation is essential to evaluate the feasibility. The potential TC barriers are: complexity in finding information and a reliable professional, complexity in determining the cost and benefit, and time and effort to find available and appropriate measures. The cognitive burden of making complex and irreversible decisions is also part of TC barriers at this phase [480, 481].

Planning

In the planning phase, householders need to investigate different aspects of the renovation procedure, including the essential permits they require before conducting the renovation [320, 425, 478]. The time and effort involved in searching for a reliable expert to help them with finding the essential information are the main TC in this phase. Imperfect or asymmetric information may increase that particular TC [313].

Decision

Householders usually do not have sufficient technological knowledge and are not construction experts. Therefore, they need to rely on experts [64, 213, 425, 480]. Before implementation, renovators need to find a reliable contractor to carry out the work that they are not willing to do or cannot do themselves. The subsidies and loans by public authorities might influence the decision, especially when they lack the necessary resources. At this phase, the complexity in finding a reliable contractor and obtaining subsidies and loans can be sources of TCs. Awareness of the advantages of renovation is a motivator when making decision in relation to the aforementioned TCs.

Executing

Householders explore the renovation activities in which they have to be involved and how much hassle and mess the renovation may cause. At this stage, TCs are disruption in the ordinary life, the hassle factor during the renovation, and the complexity of implementing the renovation [480]. Additionally, lack of trust in the relationship between the contractor and householder might increase the TCs at this phase.

Experiencing

After decision-making and implementation, the householder's experiences are disseminated through social networks [481]. The householder should also find the next step of the renovation, such as whether a complementary renovation is necessary. Finding such information is a TC barrier in this stage. Figure 5.2 summarises the TCs at different phases of the decision-making process.

5.3 Methodology

5.3.1 Database

A questionnaire survey was conducted among 3,776 homeowners in the Netherlands (Appendix A). The questionnaire comprised three sections: household and building characteristics, renovation (two categories: exterior and interior), and energy efficiency renovation. Homeowners were asked whether or not they had implemented a renovation in the last two years, and whether or not they planned a renovation in the next two years.

To evaluate the representativeness of our sample set in the homeowner sector of the Netherlands, we compared a few variables of our sample with the Woon energy module dataset 2012; Figure 5.3 shows the results of this comparison. In both datasets, the highest share belongs to dwellings constructed between 1971 and 1990 where the percentages are 29% and 35%, respectively. For the periods 1945 to 1970 and after 1991 the percentagesfrom the two data sets are very close.

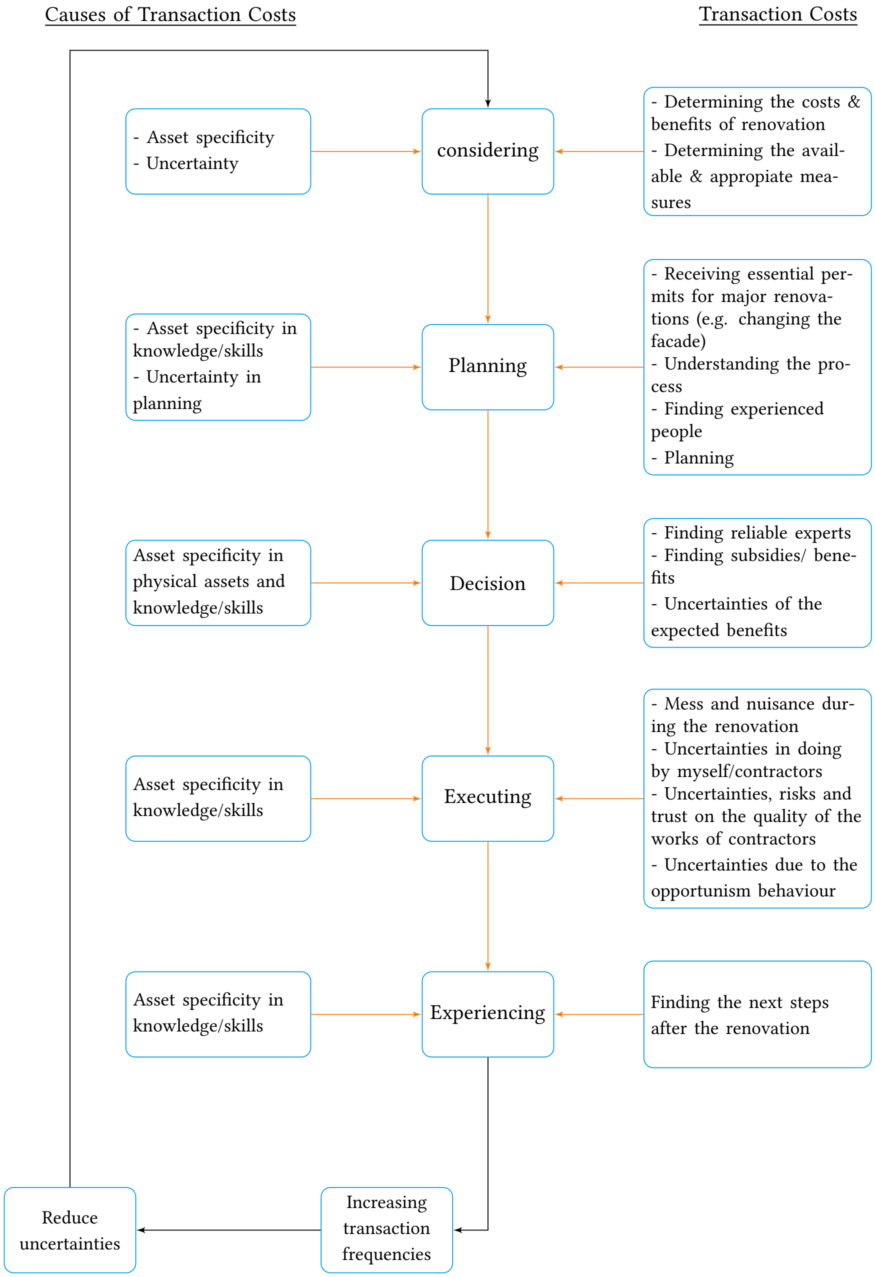

FIG. 5.2 Transaction costs at different stages of a renovation based on the literature review

In both samples the, The majority of houses in the sample are intermediate houses. However, the percentage of intermediate houses in our sample is greater than the one in Woon energy module 2012. The percentage of corner houses is more in our sample. See Figure 5.4.

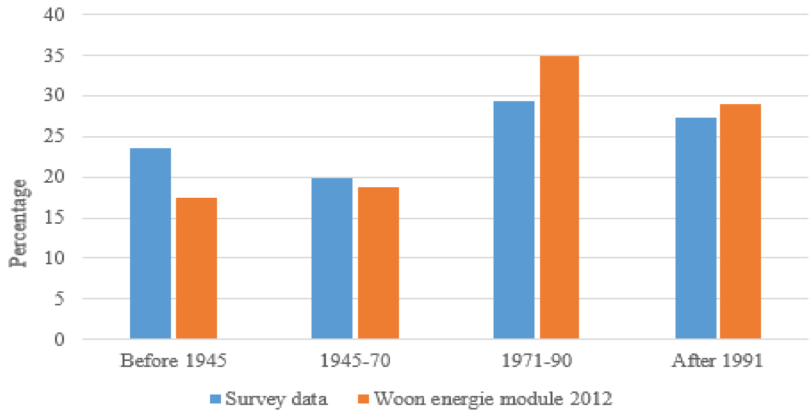

FIG. 5.3 Comparison of construction periods of survey data vs. Woon energy module 2012

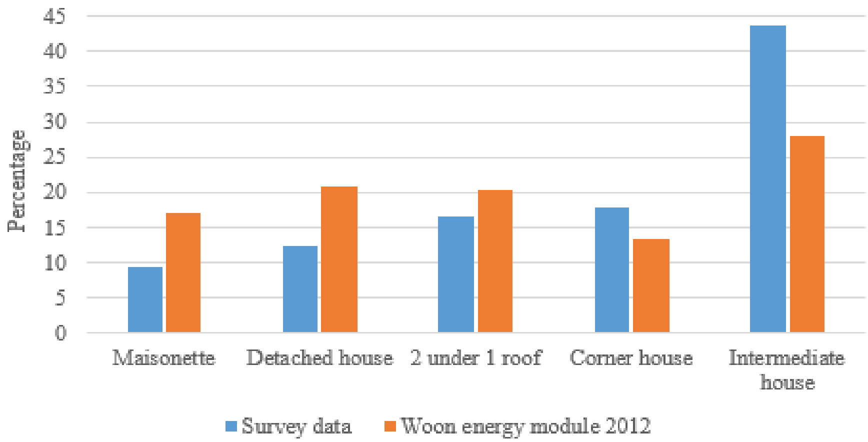

FIG. 5.4 Comparison of dwelling types of survey data vs. Woon energy module 2012

Considering the age distribution, 47% of respondents belong to the age group between 45 and 64 years old. The percentages are approximately similar for all age groups in both datasets. Similar patterns are followed in both datasets for education, with the highest percentage belonging to the professional education group and householders with university degrees. See Figure 5.5 and Figure 5.6.

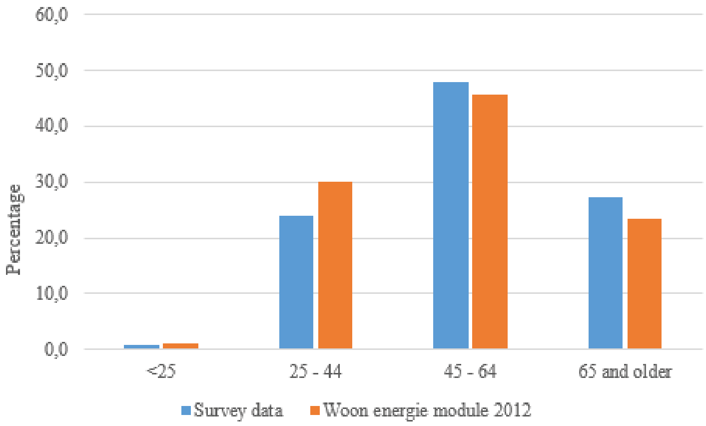

FIG. 5.5 Comparison of age of respondents of survey data vs. Woon energy module 2012

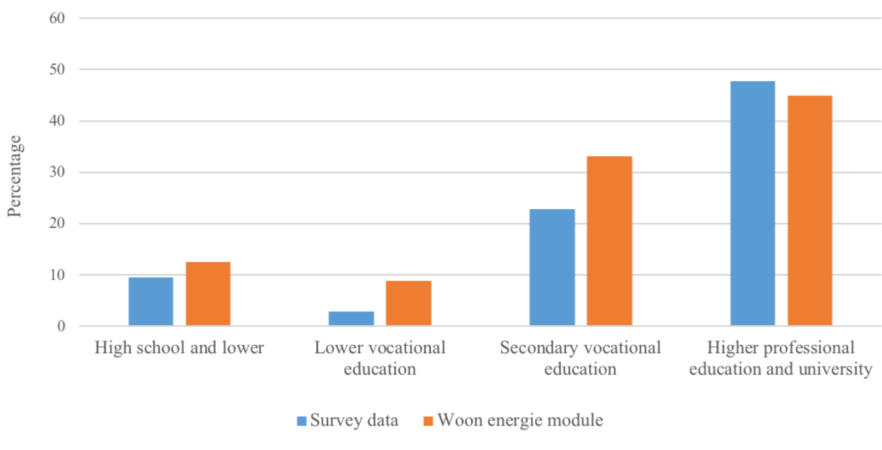

FIG. 5.6 Comparison of education of respondents of survey data vs. Woon energy module 2012

Table 5.2 shows the number of people, type of family, and householder incomes of the Woon energy module dataset. Tables 5.4 and 5.5 provide the same information from of our survey dataset. Since the categories and scales of income are different for these two datasets, no comparison can be made for the income categories.

TABLE 5.2 Data from Woon energy model dataset 2012.

Variable	Categories	Frequency	Percent
Number of people in the household	1	604	21.7
	2	1195	42.9
	3	343	12.3
	4	448	16.1
	5 and more	194	5.7
one / multiple family	Single	2316	83.2
	Multi	468	16.8
Household income (Euro per year)	<=13,000	68	2.4
	13,000 - 26,000	244	8.8
	26,000 - 38,000	527	18.9
	38,000 - 51,000	508	18.2
	51,000 - 63,000	434	15.6
	63,000 - 76,000	387	13.9
	76,000 - 89,000	224	8.0
	89,000 - 100,000	151	5.4
	>=100,000	240	8.6

5.3.2 Different types of renovation

Different types of renovations are categorised in table 5.3. The questionnaire questions apply to all types of renovation, regardless of whether they are exterior/ interior renovations or energy efficiency renovations.

TABLE 5.3 Categorisation of different types of renovations.

Type of renovation		Subtype of renovation
Renovation	**Exterior**	Roof construction/covering, Gutters/ drainpipes, Masonry/ jointing of the façade,
		Wood/ painting outside, new installation/ extension, Foundation repair
	Interior	Inner walls, Kitchen, Toilet and bathroom, Paint / wallpapering / tiling, electricity
Energy efficiency renovation		CV boiler, ventilation, roof insulation, glass insulation, floor insulation, facade/
		cavity insulation, insulation of the pipes, solar panels, solar water heater, heat pump

5.3.3 Household profile and building characteristics

Table 5.4 shows the respondent characteristics. The majority have a professional qualification, with 32.3% of householders earning between 1,800-3,150 euro per month and 24.2% receiving more than 3,150 euro per month.

61.6% of houses have one or two inhabitants, which is a very close to the 70.5% reported in Eurostat [131] for the entire country.

TABLE 5.4 Homeowners' profile.

Homeowners' profile	Categories/Average	Frequency	Percentage
Age	<25	27	0.7
	25–44	782	20.7
	45–64	1566	41.5
	65–105	890	23.6
Education	High school and lower	363	9.6
	Lower vocational education	104	2.8
	Secondary vocational education	862	22.8
	Higher professional education	1216	32.2
	University	589	15.6
Average net monthly income of respondents (Euro per month)	Lower than 1000	37	1.0
	1000–1350	101	2.7
	1350–1800	416	11.0
	1800–3150	1218	32.2
	More than 3150	915	24.2
Planning to move within 2 years	Yes	228	6.0
	No	2644	70.0
	Probably	666	17.6

TABLE 5.5 Building characteristics.

Building characteristics	Categories/ Average	Frequency	Percentage
Number of people in the house	1	781	20.7
	2	1,544	40.9
	3	393	10.4
	4	390	10.3
	5 and more	133	3.5
One/ multifamily	Multi	1,186	31.4
	Single	2,336	61.9
Construction period	Before 1945	622	16.5
	1945–1970	670	17.7
	1971–1990	1,252	33.2
	After 1990	1,041	27.6
Type of house	Apartment	942	24.9
	Detached house	317	8.4
	2 under 1 roof	428	11.3
	Maisonette	244	6.5
	Corner house	464	12.3
	Middle house	1,127	29.8

5.3.4 Method of Analysis

In the survey, respondents are asked whether they have done renovations in the past or are planning to do any renovation in the up-coming years. The answers to these questions are: a) Yes (1), b) No (0). The number of respondents for different types of renovations are listed in table 5.6:

TABLE 5.6 Number of respondents for different types of renovations.

Group	Renovators	Potential renovators
Exterior	1,958	1,353
Interior	1,826	1,035
Energy efficiency renovation	1,008	342

Renovators

TC barriers: renovation vs. energy efficiency renovation. Figure 5.7 shows the importance of complexities from the renovator perspectives of the renovation (exterior and interior) and energy efficiency renovations. For renovation (exterior and interior types), the main identified complexities are carrying out the renovation, determining the costs, and finding a reliable professional/contractor. The least important factors are finding financial support, determining the state of maintenance, and making the house more energy efficient.

For energy efficiency renovations, the influencing TC barriers are similar to the renovations. However, 19% of respondents mentioned a high degree of complexity involved in finding the best way to make their house more energy efficient.

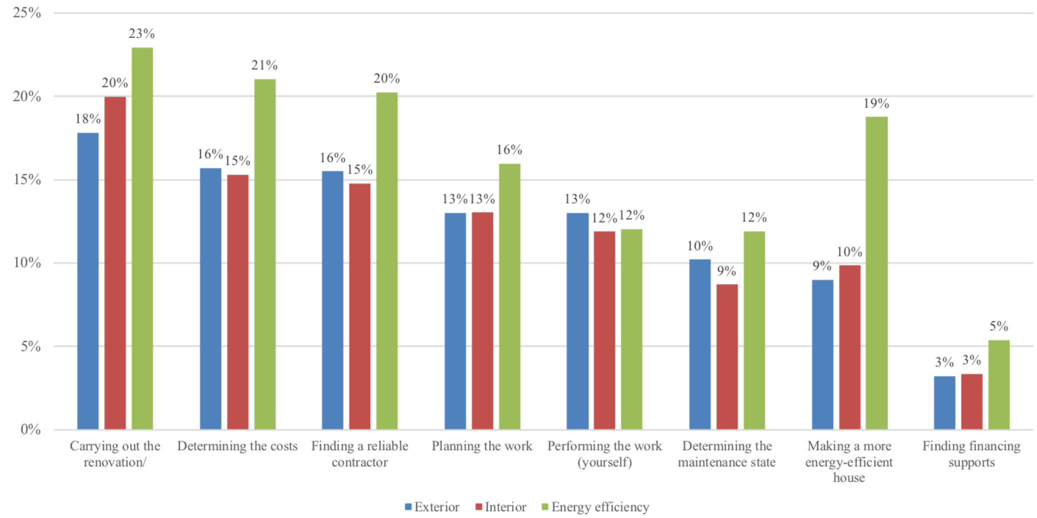

FIG. 5.7 Ranking the TCs barriers by renovators

Information: renovation vs. energy efficiency renovation. Figure 5.8 demonstrates the importance of sources of information for renovations (exterior and interior) and energy efficiency renovations. For renovations, the main identified sources are the maintenance/installation companies, family/friends, and Internet.

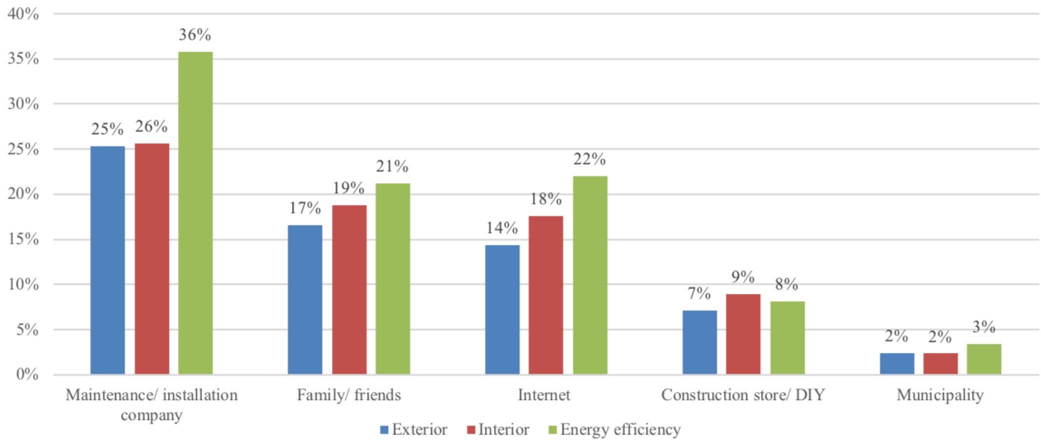

FIG. 5.8 Ranking the sources of information by renovators

Potential renovators

TC barriers: Renovation vs. energy efficiency renovation. Figure 5.9 shows the importance of TC barriers for potential renovators. For the exterior, the main identified factors are in determining the costs, looking for a reliable professional and carrying out the renovation. The least important TCs are in determining the maintenance state, planning the work, and performing the work themselves.

For the interior renovations, the main identified TCs are in determining the costs, carrying out the renovation, and finding a reliable professional. Determining whether the house maintenance is adequate is the least important TC. For the energy efficiency renovations, the main identified TCs are determining the costs, making the house more energy efficient, and finding funding/ financing options. The least important ones are in determining the adequate maintenance of the house, planning the work, and performing the work themselves. The main difference is that finding a reliable professional and maximising energy efficiency is ranked higher for energy efficiency renovations.

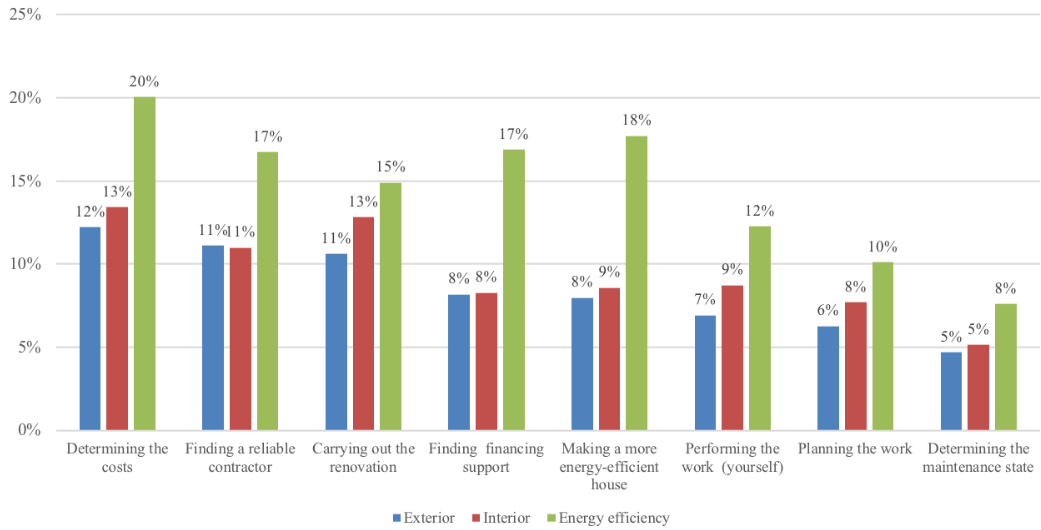

FIG. 5.9 Ranking the stages of TCs barriers by potential renovators

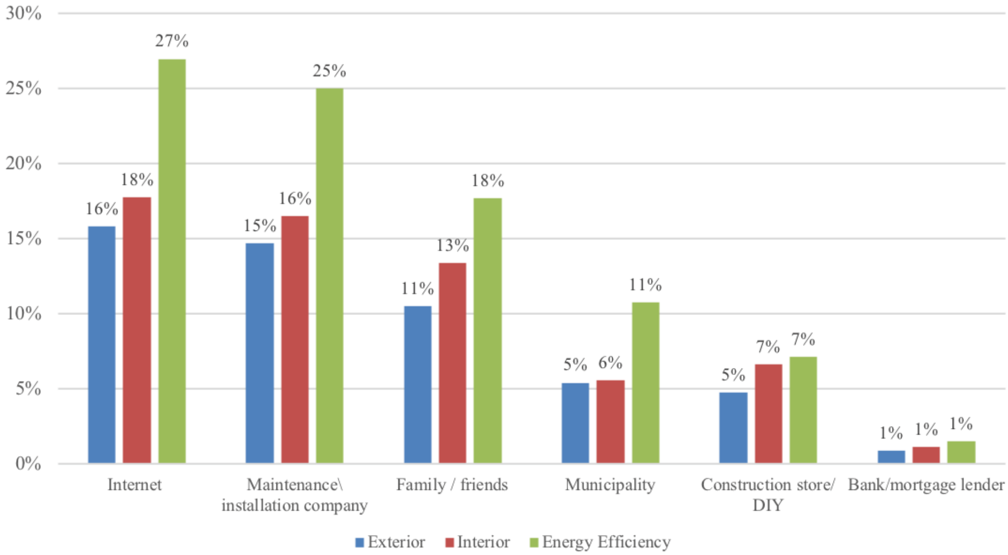

FIG. 5.10 Ranking the sources of information by potential renovators

Information: Renovation (exterior and interior) vs. energy efficiency renovation. Figure 5.10 shows the selected sources of information by potential renovators. For all types of renovations, the main identified sources are the Internet, maintenance/installation companies, and family/friends. The least important sources are banks/mortgage lenders and municipalities.

Ranking the sources of information by potential renovators

Transaction costs in the decision-making process of renovation

The questionnaire survey asked general questions about the main TC factors and sources of information for the renovation. These questions were answered for each type of renovation (exterior, interior, and energy efficiency renovation).

The importance of TC barriers at different stages of the decision-making process of renovation and the sources of information are investigated using logistic regression. In the analysis, the binary dependent variable is the renovation decision, and some assumptions are made. In total, we have estimated six regressions for renovators and potential renovators. For each group, three regressions are estimated for the renovations (exterior and interior), and energy efficiency renovations. The question was whether the homeowner implemented/planned to do the renovation in the last/next 2 years. The independent variables are the household and building characteristics, the sources of information, TC barriers, motivation, and the state of maintenance of a specific renovation.

Table 5.7 shows a logistic regression output in Statistical Package for the Social Sciences (SPSS). Coefficient B indicates the changes in log of the dependent variable for every one-unit change in an independent variable. Odds ratios (column exp(B)) explain the degree of association between dependent and independent variables and are used to compare the relative probabilities of the occurrence (chance criterion) of the renovation, given the presence of variable such as TC barriers. For the variables with categories, generally the chance criterion is compared with the reference category. Binary variables can be seen as category variables with only two categories. The percentages of selecting the category *j* by respondents can be calculated using the chance criterion $(exp\,(\beta_j)/(\sum_{i=1}^{n} exp\,(\beta_j) \times 100)$. A Wald test demonstrates the significance of each coefficient in the regression.

TABLE 5.7 SPSS outputs for logistic regression.

Independent variables	B	S.E.	Wald	df	Sig.	Exp(B)
Constant						

There are some assumptions in conducting logistic regressions, including the binary dependent variable, not having multicollinearity between independent variables, and a large sample size. Validity of the multicollinearity assumption is verified by calculating the Variance Inflation Factors (VIF). The VIF = 2.5 is the initial point of concern and VIF>10 shows multicollinearity [298]. The VIF for the six regressions are presented in Table 5.8. There is no serious multicollinearity between the independent variables in the sample.

TABLE 5.8 Multicollinearity tests in six regressions.

Regression	max VIF
Renovators	
Renovations - exterior	1.484
Renovations - interior	1.254
Energy efficiency renovations	1.202
Potential renovators	
Renovation - exterior	1.460
Renovation - interior	1.538
Energy efficiency renovations	1.731

Binary logistic regression model used to describe the relation between the dependent variable and independent variables is presented in eq. (5.1):

$$Log\left(\frac{P_{\text{renovation}}}{(1-P_{\text{renovation}})}\right) = \beta_0 + \beta_1 X_{\text{households and buildings' characteristics}} + \beta_2 X_{\text{motivations for renovations}} \\ \beta_3 X_{\text{sources of information}} + \beta_4 X_{\text{TCs barriers}} + \beta_5 X_{\text{State of maintenance for each type}} \quad (5.1)$$

where P is the probability of the events, and X represents independent variables. After estimation, the Omnibus tests of model coefficients and the Hosmer and Lemeshow test are applied to validate the models, as shown in Table 5.9. The Omnibus test checks whether the model estimates the outcome with the explanatory variables better than without [55]. The Omnibus tests are statistically significant, and the models are better with explanatory variables than without. The Hosmer and Lemeshow test illustrates the goodness of fit, which is a significant factor for a good model.

TABLE 5.9 Assessing the regressions regarding the goodness of fit.

	Omnibus Tests of Model Coefficient			Hosmer and Lemeshow Test			R^2
	Chi-square	df	Sig.	Chi-square	df	Sig.	
Renovators							
Exterior	132.871	33	0.000	13.021	8	0.111	0.223
Interior	143.216	27	0.000	8.465	8	0.389	0.231
Energy efficiency	127.343	31	0.000	2.664	8	0.954	0.192
Potential renovators							
Exterior	41.174	23	0.011	9.366	8	0.312	0.143
Interior	99.938	35	0.000	11.532	8	0.173	0.357
Energy efficiency	109.455	33	0.000	8.887	8	0.352	0.336

5.4 Results

The importance of TC barriers was investigated using regression analysis. We estimated six regressions for exterior, interior, and energy efficiency renovations for renovators and potential renovators.

5.4.1 Renovators

Regression analysis

Exterior type of renovation. Table 5.10 shows the result of logistic regression for exterior type of renovations. Among socioeconomic factors, income and education have a significant impact on renovation decisions. Higher income and education result in higher probability of exterior type of renovations. For instance, renovators with an income of more than 3150 euro are 2.3 times more likely to perform an exterior renovation compared to the income group with less than 1350. Regarding the building characteristics, the regression shows a relationship between building types and exterior type of renovations. Corner and detached houses are more likely to renovate the exterior of buildings compared to apartments.

The significant TC barriers are in determining the state of maintenance of the house by experts and in doing the work themselves, as identified by 68% and 62% of respondents indicated that these TC barriers were difficult to handle respectively. These are all TC barriers that hinder the process of doing exterior type of renovations (execution phase). It can be concluded from the complexities of exterior type of renovations that householders need the help of an expert. The main identified source of information verifies this result. 62% of respondents indicate construction stores and Do-It-Yourself (DIY) companies as the main source of information for exterior type of renovation. The second significant source of information is via internet with 40% of respondents indicating the importance of this information source. The conditions of different types of exterior renovations are included in the analysis to investigate on which types of exterior renovation the householders invest. Based on the regression, householders are more likely to perform renovations when the states of maintenance of outside wood and painting and foundation are not good; these influencing factors were mentioned by 80% and 76% of respondents respectively. The state of glass insulation is also significant and triggers householders to renovate their windows.

TABLE 5.10 Logistic regression for the exterior type of renovation in the last 2 years

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Income- Ref: less than 1350			11.857	3	0.008	
(a) 1350–1800 euro	-0.224	0.487	0.211	1	0.646	0.799
(b) 1800–3150 euro	0.375	0.448	0.701	1	0.402	1.455
(c) more than 3150 euro	0.813	0.465	3.054	1	0.081	2.254
Education- Ref: high school and less			9.406	4	0.052	
(a) Lower vocational education	-1.348	0.631	4.558	1	0.033	0.260
(b) Secondary vocational education	-0.481	0.352	1.870	1	0.172	0.618
(c) Higher professional education	-0.223	0.340	0.430	1	0.512	0.800
(d) University	0.193.	0.389	0.246	1	0.620	1.213
Type of house- Ref: Apartment			30.812	5	0.000	
(a) Detached	-0.646	0.409	2.498	1	0.114	0.524
(b) 2 under 1 roof	-1.586	0.338	22.064	1	0.000	0.205
(c) Maisonette	-0.353	0.445	0.631	1	0.427	0.702
(d) Corner house	-1.335	0.324	17.029	1	0.000	0.263
(e) Middle house	-1.184	0.280	17.835	1	0.000	0.306
TC:(a) In determining the maintenance state of house	0.756	0.261	8.387	1	0.004	2.130
(b) In performing the work (yourself)	0.515	0.243	4.496	1	0.034	1.673
(c) In finding a reliable contractor	0.313	0.207	2.294	1	0.130	1.368
Information: (a) Internet	-0.391	0.204	3.688	1	0.055	0.676
(b) Family/ friends	0.378	0.204	3.422	1	0.064	1.459
(c) Construction store / do it yourself company	0.474	0.195	5.935	1	0.015	1.606
State of maintenance: (a) Wood and paint outside	1.483	0.329	20.335	1	0.000	4.405
(b) Foundation	1.168	0.535	4.775	1	0.029	3.217
(c) Glass insulation	-0.937	0.420	4.961	1	0.026	0.392
Constant	0.231	1.455	0.025	1	0.874	1.260

Interior type of renovation. Table 5.11 shows the result of logistic regression for interior type of renovations. Younger householders are more willing to renovate. Householders in the age group of less than 44 are 2.40 times more likely to renovate their houses compared to householders in the 64-105 age group. Respondents who indicated that they are planning to move within 2 years are 1.5 times more likely to renovate the interior part of the houses compared to the ones that plan to stay. Householders with the highest income (more than 3.150 euros) are 2.23 times more likely to renovate the interior of the house compared to the group with the least income (less than 1,350 euros). The coefficients of different levels of education are not significant and no relationships can be found with renovating the interior of houses and education. There is a significant relationship between the building type and interior renovation. Detached and 2 under 1 roof homeowners are 3 and 2.6 times respectively more likely to renovate compared to apartment owners.

Householders did not indicate any complexities for conducting the actual work for interior types of renovations. The only significant TC barriers regarding the complexities is on determining the costs of doing these renovations. Approximately 40% of respondents mentioned this TC barrier as important. On the other hand, the information sources are very important and have a considerable impact on the interior renovation decision-making process. The main identified sources of information are construction stores and DIY companies. In the Netherlands, DIY companies supply the components that the consumers need for undertaking house renovations by themselves. These companies have all the necessary building materials and components. They also support their customers by providing information.

These results show that the majority of interior renovations are done by householders themselves. This is consistent with the fact that they did not mention complexities in finding a reliable professional/contractor but did mention that all sources of information, especially from DIY companies, are very important. 61% and 67% of respondents mentioned construction stores/DIY and the Internet as the main sources of information. The municipality seems not to be a chosen source of information for interior types of renovations. The coefficient of this variable is not significant in the regression analysis. There is no statistically significant relationships between the state of maintenance of interiors and renovations. One close to a significant coefficient (90% confidence interval) is for painting, wallpaper and tile work.

TABLE 5.11 Logistic regression for the interior type of renovation in the last 2 years.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Age group- Ref: less than 44			14.262	2	0.001	
(a) 44–64	−0.185	0.231	0.641	1	0.423	0.831
(b) 64–105	−0.875	0.260	11.366	1	0.001	0.417
mover-stayer(1)	0.416	0.206	4.070	1	0.044	1.516
Income- Ref: less than 1350			4.326	3	0.228	
(a) 1350–1800 euro	0.738	0.476	2.398	1	0.122	2.091
(b) 1800–3150 euro	0.516	0.434	1.418	1	0.234	1.676
(c) more than 3150 euro	0.800	0.453	3.125	1	0.077	2.226
Type of house- Ref: Apartment			19.144	5	0.002	
(a) Detached	1.132	0.373	9.237	1	0.002	3.103
(b) 2 under 1 roof	0.946	0.321	8.674	1	0.003	2.575
(c) Maisonette	0.135	0.327	0.170	1	0.680	1.144
(d) Corner house	0.846	0.307	7.599	1	0.006	2.329
(e) Middle house	0.710	0.237	8.954	1	0.003	2.034
TC: In determining the costs	−0.486	0.199	5.963	1	0.015	0.615
Information: (a) Internet	0.725	0.216	1.249	1	0.001	2.064
(b) Family/ friends	0.461	0.202	5.215	1	0.022	1.585
(c) Construction store/ Do it yourself company	1.150	0.349	10.876	1	0.001	3.159
(d) Maintenance/ installation company	0.465	0.193	5.782	1	0.016	1.592
State of maintenance: paint, wallpaper and tile work	0.842	0.552	2.325	1	0.127	2.322
Constant	−0.929	1.143	0.660	1	0.416	0.395

Energy efficiency renovations. Table 5.12 shows the logistic regression for energy efficiency renovations that are conducted in the last two years by the renovators. The income variable is significant, however the coefficients of different categories of income are not significant. Therefore, it cannot be stated that the higher income householders have done more energy efficiency renovations. Higher education levels show significant coefficients for two categories of secondary vocational and higher professional educations. Householders with higher professional educations are twice as likely to renovate the houses to make them more energy efficient. The coefficient of university degree is not significant and no conclusion can be made for this group of householders.

The coefficient of building type variable is significant. However, for the sub-categories of this variable, only the coefficient for the detached houses is statistically significant. Homeowners with detached houses have more probability to renovate their house energy efficiently compared to other building types. The householders with detached houses are 1.8 times more likely to renovate their houses more energy efficiently compared to the householders with apartments.

Among the TC barriers, only one has a highly significant coefficient. Householders indicated the complexities in determining the ways to increase the energy efficiency of their houses as the main TC barrier. 83% of householders that renovated their houses more energy efficiently mentioned this barrier as being very significant.

The sources of information show statistically significant coefficients. Among sources of information, maintenance and installation companies have higher significant impact compared to other sources. The coefficients for maintenance and installation companies and construction stores/DIY companies are also significant. 59% and 37% of householders that renovate their houses more energy efficiently indicated the maintenance/installation and construction store/DIY companies as the main sources of information, respectively. The coefficient for the Internet as a source of information is also close to being statistically significant. The least significant sources of information regarding energy efficiency renovations are family/friends and municipalities.

The comfort levels of humidity and flow of fresh air has statistically significant impacts on energy efficiency renovation decisions. 27% of respondents mentioned that the level of comfort of fresh air would be reason for a renovation, while for humidity it was 67% with a confidence interval of 90%.

TABLE 5.12 Logistic regression for energy efficiency renovation decision in the last 2 years.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Income- Ref: less than 1350			6.849	3	0.077	
(a) 1350–1800 euro	−0.117	0.446	0.068	1	0.794	0.890
(b) 1800–3150 euro	−0.197	0.408	0.234	1	0.629	0.821
(c) more than 3150 euro	−0.632	0.420	2.260	1	0.133	0.532
Education- Ref: high school and less			6.972	4	0.137	
(a) Lower vocational education	0.933	0.602	2.407	1	0.121	2.543
(b) Secondary vocational education	0.495	0.298	2.765	1	0.096	1.641
(c) Higher professional education	0.661	0.283	5.455	1	0.020	1.937
(d) University	0.367	0.308	1.418	1	0.234	1.444
Type of house- Ref: Apartment			9.852	5	0.080	
(a) Detached	0.576	0.315	3.344	1	0.067	1.778
(b) 2 under 1 roof	0.394	0.280	1.970	1	0.160	1.482
(c) Maisonette	−0.391	0.321	1.483	1	0.223	0.677
(d) Corner house	−0.060	0.264	0.052	1	0.819	0.941
(e) Middle house	0.264	0.219	1.443	1	0.230	1.3021302
TC:(a) In determining the ways to increase energy efficiency	1.609	0.208	59.868	1	0.000	4.997
Information: (a) Internet	0.265	0.175	2.285	1	0.131	1.303
(b) Construction store/ Do it yourself company	−0.509	0.222	5.249	1	0.022	0.601
(c) Maintenance/ installation company	0.387	0.167	5.336	1	0.021	1.472
State of maintenance: (a) Humidity	0.708	0.422	2.822	1	0.093	2.031
(b) Flow of fresh air	−0.998	0.498	4.014	1	0.045	0.369
Constant	−1.860	1.621	1.316	1	0.251	0.156

5.4.2 Potential renovators

Regression analysis

Exterior types of renovations. Table 5.13 shows the results of logistic regression for potential renovators for the exterior of buildings. The coefficient of age group is significant. The respondents younger than 44 are 2.1 times more likely to plan a renovation compared to respondents in the 44-64 age range. Education also has a significant impact on planning for a renovation. Respondents with university degrees are 2.8 times more likely to plan for a renovation compared to respondents with high school certificate or less. The coefficient of professionally qualified respondents is close to a 90% confidence interval and this group are 1.9 times more likely to plan for a renovation compared to the reference group.

The coefficients of sources of information are not significant. Among the TC barriers, finding a good professional/ contractor is the main identified one. 65% of respondents who plan to renovate, mentioned it as the main barrier for exterior types of renovations. The second most significant TC barrier (close to 90% confidence interval) is in determining the best ways to achieve energy efficiency. 39% of respondents mentioned the significance of this barrier. The third TC barrier (close to significant) is on determining the maintenance state of the house, with 38% of respondents predicting to have difficulty with this barrier. As expected for potential renovators, TC barriers on the implementation phase are not significant, such as in performing the work. This might be due to the fact that people do not have an overall picture of the whole renovation process.

The state of maintenance of exterior parts of buildings has a significant impact on planning for a renovation. The main identified maintenance states are 'masonry and jointing of the facade' and 'wood and paint outside'. Approximately 30% of respondents mentioned these maintenance issues as important for planning a renovation of the exterior of their building.

TABLE 5.13 Logistic regression on the planning of exterior types of renovations in the next 2 year.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Age group- Ref: less than 44			8.018	2	0.018	
(a) 44–64	−0.722	0.318	5.148	1	0.023	0.486
(b) 64–105	0.039	0.442	0.008	1	0.930	1.040
Education- Ref: high school and less			11.021	4	0.026	
(a) Lower vocational education	−1.645	0.986	2.788	1	0.095	0.193
(b) Secondary vocational education	0.366	0.456	0.644	1	0.422	1.442
(c) Higher professional education	0.645	0.424	2.319	1	0.128	1.907
(d) University	1.033	0.470	4.825	1	0.028	2.809
Information: Family/ friends	−0.396	0.285	1.935	1	0.164	0.673
TC: (a) in determining the maintenance state	−0.460	0.317	2.108	1	0.147	0.631
(b) in determining the ways to increase energy efficiency	−0.443	0.284	2.434	1	0.119	0.642
(c) finding a reliable professional	0.642	0.295	4.719	1	0.030	1.900
State of maintenance: (a) Masonry and jointing of the façade	−0.906	0.465	3.796	1	0.051	0.404
(b) Wood and paint outside	−0.881	0.431	4.177	1	0.041	0.414
Constant	4.269	1.358	9.887	1	0.002	71.415

Interior types of renovations. Table 5.14 shows the logistic regression for potential renovators planning to renovate the interior of their building. The coefficients of age, income, and education levels are not significant for planning an interior renovation. Respondents that are planning to stay are 1.9 times more likely to plan for interior renovations compared to the movers. The confidence interval for this coefficient is close to 90%.

Regarding building characteristics, there could be a relationship between type of buildings and planning for interior types of renovations. Middle houses and 2 under 1 roof houses have statistically significant coefficients and they are respectively 3.5 and 2.8 times more likely to plan for interior renovations compared to apartments. The coefficient of houses constructed between the years 1945 and 1970 is significant. Respondents in this category are 2.4 times more likely to plan for a renovation compared to respondents in houses built before 1945.

Few information sources have statistically significant coefficients. The most significant one is the construction store/DIY companies with 84% of respondents mentioned the importance of this source. The second significant source of information is family/friends with 69% of respondents mentioning the importance of this source. The coefficient of the Internet source has close to a 90% confidence interval significance with 63% of respondents. The least significant sources of information are from municipalities and maintenance/ installation companies.

Significant relationships exist between TC barriers and planning to renovate interior parts of buildings. The main identified TC barrier is in determining the best way to do the interior renovations with 65% of respondents mentioning the importance of this barrier. ’The ways to increase energy efficiency’ and ’finding a good professional/ contractor’ are also significant, although the coefficients are negative. The coefficients of maintenance are not significant.

TABLE 5.14 Logistic regression for the planning interior types of renovation decisions in the next 2 years.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
mover-stayer(1)	−0.640	0.403	2.514	1	0.113	0.527
Education-Ref: high school and less			5.457	4	0.244	
(a) Lower vocational education	−2.035	1.150	3.134	1	0.077	0.131
(b) Secondary vocational education	0.037	0.645	0.003	1	0.954	1.038
(c) Higher professional education	−0.219	0.583	0.141	1	0.707	0.803
(d) University	−0.636	0.636	1.000	1	0.317	0.530
Type of house- Ref: Apartment			16.033	5	0.007	
(a) Detached	0.513	0.566	0.822	1	0.365	1.670
(b) 2 under 1 roof	1.013	0.580	3.050	1	0.081	2.755
(c) Maisonette	−0.803	0.632	1.614	1	0.204	0.448
(d) Corner house	0.860	0.541	2.528	1	0.112	2.363
(e) Middle house	1.254	0.460	7.434	1	0.006	3.506
Construction year - Ref: <1945			4.269	3	0.234	
(a) 1945-70	0.877	0.514	2.918	1	0.088	2.404
(b) 1971-90	0.022	0.440	0.003	1	0.960	1.022
(c) >1991	−0.067	0.477	0.020	1	0.888	0.935
Information: (a) internet	0.521	0.355	2.161	1	0.142	1.684
(b) family/ friends	0.836	0.351	5.692	1	0.017	2.308
(c) construction store / do it yourself company	1.682	0.566	8.828	1	0.003	5.375
TC:(a) in determining the best way to do the renovation	0.625	0.329	3.603	1	0.058	1.868
(b) in determining the ways to increase energy efficiency	−1.042	0.367	8.045	1	0.005	0.353
(c) in planning the work	0.597	0.415	2.068	1	0.150	1.817
(d) finding a reliable professional	−0.767	0.353	4.713	1	0.030	0.464
Constant	3.231	2.535	1.625	1	0.202	25.317

Energy efficiency renovations. Table 5.15 shows the results of logistic regression for potential renovators and energy efficiency renovations. The socio-economic variables are not significant. Type of building is a significant variable in the regression. Respondents with apartments are 6 times more likely to plan for an energy efficiency renovation compared to respondents with corner houses.

The coefficients of information sources are significant. The main identified source of information is the Internet and maintenance/installation companies. Respectively, 66% and 65% of respondents mentioned the importance of these sources. The least significant coefficients are the construction store/DIY companies, bank/mortgage lenders, family/friends, and municipalities.

TC barriers affect energy efficiency renovations. The coefficients for some barriers are statistically significant. The first important barrier is in determining the best ways to increase energy efficiency. 74% of respondents mentioned the importance of this barrier for energy efficiency renovations. The second most significant one is in determining the best way to do the renovation. 30% of respondents confirmed the importance of this TC. The last significant coefficient (90% confidence interval) is the TC of finding financial support with 63% of respondents mentioning the importance of this barrier.

The maintenance states of the energy related parts of the buildings has significant impact on energy efficiency renovations. The roof and glass insulation have the highest significant coefficients, with respectively 20% and 24% of respondents mentioning the importance of these maintenance issues. The least important maintenance issue belongs to ground floor insulation. Although the heating system shows a significant coefficient, at about 4% the percentage is low.

TABLE 5.15 Logistic regression for energy efficiency renovation decision in the next 2 years.

Variables	B	S.E.	Wald	df	Sig.	Exp(B)
Type of house- Ref: Apartment			12.863	5	0.025	
(a) Detached	0.255	0.378	0.457	1	0.499	1.291
(b) 2 under 1 roof	0.262	0.438	0.359	1	0.549	1.3
(c) Maisonette	−0.153	0.405	0.143	1	0.705	0.858
(d) Corner house	−1.792	0.601	8.877	1	0.003	0.167
(e) Middle house	−0.627	0.379	2.736	1	0.098	0.534
Information: (a) internet	0.674	0.291	5.365	1	0.021	1.963
(b) maintenance/ installation company	0.636	0.296	4.604	1	0.032	1.889
TC:(a) in determining the best way to do the renovation	−0.876	0.266	10.817	1	0.001	0.416
(b) in determining the ways to increase energy efficiency	1.07	0.29	13.651	1	0	2.915
(c) finding financing supports	0.534	0.315	2.87	1	0.09	1.706
State of maintenance: (a) Roof insulation	−1.443	0.42	11.812	1	0.001	0.236
(b) Glass insulation	−1.106	0.434	6.495	1	0.011	0.331
(c) heating	−3.078	0.869	12.54	1	0	0.046
Constant	9.434	2.213	18.175	1	0	12.509

5.4.3 Overview of the influencing factors for the renovators and potential renovators

Tables 5.16 and 5.17 present the key socio-economic variables, TC barriers, and sources of information to make it easier to follow the regression analysis results.

TABLE 5.16 Overview of the influencing factors for renovators.

Exterior			
Socioeconomic variables	**building characteristic**	**TC barriers**	**Information**
Income	Yes	The maintenance states	construction stores/DIY companies
Education	–	Doing the work by themselves	Internet
Interior			
Socioeconomic variables	**Building characteristic**	**TC barriers**	**Information**
Age group	Yes	Determining the costs	Construction store/ Do it Yourself Companies
Income	–	–	–
Mover/ stayer	–	–	–
Energy efficiency			
Socioeconomic variables	**Building characteristic**	**TC barriers**	**Information**
Income	Yes	Complexities in determining the ways to increase the energy efficiency	Maintenance/ installation companies
Education	–	–	Internet

TABLE 5.17 Overview of the main influencing factors for potential renovators.

Exterior			
Socioeconomic variables	**building characteristic**	**TC barriers**	**Information**
Age group	No	Finding a good professional/ contractor	Family/ friends
Education		Maintenance states of the house	
		In determining the best way to carry out the renovations	
Interior			
Socioeconomic variables	**Building characteristic**	**TC barriers**	**Information**
Mover/ stayer	Yes	In determining the best way to carry out the renovations	Construction store/ Do it Yourself Company
			Family/ friends
			Internet
Energy efficiency			
Socioeconomic variables	**Building characteristic**	**TC barriers**	**Information**
	Yes	Complexities in determining the ways to increase the energy efficiency	Internet
		In determining the best way to carry out the renovations	maintenance/ installation companies
		In finding financial supports	

5.5 Discussion

5.5.1 Comparison of renovators and potential renovators

One of the aims of this study was to compare the TC barriers and the main sources of information for renovators and potential renovators. The key differences between the influencing factors of renovators and potential renovators are discussed in the following.

Exterior types of renovations

The maintenance states of wood and painting and foundations are important influencing factors for exterior types of renovations. This indicates that the majority of exterior renovations in the sample are done due to deterioration. For potential renovators, age has significant influence on planning but not for renovators. This shows that the younger generation is willing to renovate, although they cannot achieve their plans possibly because of the TC barriers. For renovators, the influence of building characteristics is significant, although the same cannot be said of potential renovators. The reason for this difference might be that there is less data for potential renovators compared to the renovators.

For renovators, the most significant TC barriers are in determining the maintenance state of the house and in carrying out the renovations by themselves.

For potential renovators, the main TC is finding a reliable professional/contractor. Considering these barriers, removing TC barrier for potential renovators might remove the barriers for renovators as well. A reliable professional/contractor can contribute in checking the maintenance state of the house, as well as reduce the complexities in doing the renovations.

construction stores/DIY companies are perceived as the main information source for renovators. This source demonstrates the need of an expert in conducting exterior types of renovations. For potential renovators, no significant source of information is identified with a 95% confidence interval. This could also be due to missing data for potential renovators.

Interior types of renovations

Age and income levels are important factors for conducting interior types of renovations by renovators. Higher renovation probability was found for younger homeowners with higher income. For potential renovators, no statistically significant socio-economic variables are identified. For both renovators and potential renovators, movers are more likely to renovate the interior of their house, which could be for selling it at a higher price.

The main TC barriers for renovators are determining the costs of the interior renovations. However, for potential renovators, the most important factor is determining the most efficient way to carry out the interior renovations. Since the TC barriers for renovators and potential renovators are related to each other, costs can be more easily estimated by providing information regarding efficient ways of renovating.

Sources of information are important influencing factors for both renovators and potential renovators, especially DIY companies. For the potential renovators, family/friends is also an important one but for renovators, the Internet is strongly significant. This shows that the interior renovations might be conducted by the homeowners themselves. For both renovators and potential renovators, there is no relationship with the maintenance states of the interior of the building.

Energy efficiency renovations

For renovators and among socio-economic variables, only education level has an impact on energy efficiency renovation decisions. Higher educated respondents have a higher probability to renovate compared to less educated people. For potential renovators, no significant relationships are found between the socio-economic variables and planning for energy efficiency renovations. For renovators, detached houses have a higher probability of being renovated for energy efficiency purposes. However, for potential renovators apartments have a higher probability.

For both renovators and potential renovators, the main TC barrier is determining the best ways to increase the energy efficiency of the houses. This barrier also has the highest impact among all the variables in the regressions. For the sources of information, maintenance/installation companies have a significant impact on energy efficiency renovations for both renovators and potential renovators. For renovators, the comfort levels of fresh air and humidity are important influencing factors. However, for potential renovators, the maintenance states of roof and glass insulation has a major impact. Therefore, renovators are concerned more with the level of comfort than with the maintenance of energy saving measures.

5.5.2 Comparison of TC barriers of different types of renovations

The second aim of this study was to compare the differences between TC barriers and sources of information for different types of renovations. The key differences between the TC barriers and sources of information for renovations and energy efficiency renovations are discussed below:

For the exterior of buildings, the main TC barriers are carrying out the renovations and finding a reliable professional/contractor. Therefore, the main TCs are on decision-making and executing the exterior renovations. For interior renovation types, the main complexities are to do with determining the costs and finding an efficient way of renovating. Therefore, the main TC barrier is at the consideration stage. Compared to other types of renovations, householders have difficulties in determining the best ways to increase the energy efficiency of their house. Therefore, the main TC barrier of energy efficiency renovations is at the consideration stage.

For all types of renovations, the sources of information have relations with TC barriers. Householders require an expert to conduct the exterior renovation and they mention the importance of construction stores/DIY companies in providing information. For accessing information on interior renovations, householders use DIY companies, the Internet, and family/friends. Finally, for energy efficiency renovations, an expert is essential to provide support and advice on the best ways to increase the energy efficiency of the house. Therefore, maintenance/installation companies are a key factor.

5.5.3 Insight for policy makers

Based on the energy agreement and energy agenda, over €100 million has been assigned for energy efficiency renovations in the owner-occupied sector [216]. The monetary policies could be more effective in combination with information provision and work complexity reduction. Reliability of a professional/contractor was mentioned as an important barrier for different types of renovations and especially for energy efficiency renovations. In the Netherlands, specialist organisations are assigned to work in close collaboration with local initiatives, residents, municipalities, housing associations and suppliers. These organisations promote the sustainability of housing in the Netherlands. They provide free consultation, free energy scans, and cheaper packages of energy saving measures for householders. Four of these organisations currently operate in the Netherlands (Reimarkt.nl) but there is a need for involvement of more parties in order to achieve energy efficiency targets.

One of the main TC barriers for energy efficiency renovation types was 'determining the ways to increase the energy efficiency of the houses'. Municipalities contribute considerably to supporting and increasing awareness of the householders in the Netherlands. The examples are explained extensively in the latest articles published by Meijer, et al., [292]; Ebrahimigharehbaghi, et al. [112]. The energy desks (energieloket.nl) of 200 municipalities provide tailor-made solutions and advice regarding energy efficiency and improving comfort levels. One stop shop/pop up stores provide energy saving solutions at the neighbourhood level and individual building level and are contributing to reducing TC barriers.

In the climate agreement [133], development of a digital platform has been proposed to bring together the demand and supply side of energy efficiency renovations with a neighbourhood-oriented approach. The digital platform can play a role in bundling the demand and provide attractive offers for householders. Before joining the platform, the suppliers are assessed qualitatively to guarantee the services provided through the platform. From householders' perspective, the advantages of using this type of digital platforms are basically information provision and search cost (money and time) reduction. Moreover, householders can have access to a larger network of suppliers, and have higher trust in suppliers due to quality assessments, cheaper prices, etc. [114, 132].

For the public authorities, a key question is what type of information needs to be distributed to different agents, such as municipalities , suppliers, and more importantly to householders. They have to find ways to make the overall process far more efficient. To answer this question, a comprehensive study is essential to consider the interests of all the agents involved and their interaction with others.

5.6 Conclusions

This study evaluated the TC barriers and sources of information for different types of renovations (exterior, interior, and energy efficiency renovations) and for two groups of householders (renovators and potential renovators). TCs negatively influence the renovation decision-making process and reduces the effectiveness of policy instruments, such as subsidies and tax reductions on energy efficiency measures. Following the institutional economist, a conceptual framework of TCs on different stages of decision-making process of renovations was developed. Using the theoretical framework, statistical and regression analysis were conducted on data gathered from a questionnaire survey of 3,775 homeowners in the Netherlands to evaluate the significance of TC factors and identify the main ones. From the results of the study the following can be concluded:

1. The main identified TCs are in the consideration, decision, and executing phases of the different types of renovations. Executing exterior renovations and finding a reliable professional/ contractor to do exterior renovations, determining costs for interior renovations and finding ways to increase the energy efficiency of renovations are the main identified TC factors.

2. For exterior renovations and energy efficiency renovations, the main source of information is construction stores/DIY companies and maintenance/installation companies, respectively. For interior renovations, householders use DIY companies, the Internet, and family/friends and are strongly influenced by these sources of information.

3. TC factors are related to the type of renovations. For instance, renovators have difficulties in finding out the most efficient ways to renovate for energy efficiency. However, the influence of this factor is not significant in non-energy efficiency renovations.

4. Renovators mentioned TC barriers at later stages of the decision-making processes, such as carrying out the exterior renovations. However, potential renovators identified TC barriers at the early stages, such as finding the most efficient ways to carry out interior renovations. Therefore, the perspectives of these two groups are complementary for explaining TC barriers in the whole renovation process chain.

6 Validations of the main findings by policy makers and practitioners

Minor revision: Ebrahimigharehbaghi, S., Qian, Q.K., de Vries, G. and Visscher, H.J., 2022. Municipal governance and energy retrofitting of owner-occupied homes in the Netherlands. Energy Reports, 215, p.109849. PhD candidate conducted the conceptualisation, methodology, formal analysis, writing, conducted the semi-structuerd interviews and focus group sessions together with the supervisory team, revision.

Note: The previous chapters assessed the main factors influencing behaviour and transaction cost barriers in the implementation of energy retrofits. This chapter validates the findings of the previous studies from the perspective of policy makers and practitioners. The methods of data collection are semi-structured interviews and focus group meetings.

ABSTRACT

The building sector is responsible for more than one-third of global greenhouse gas (GHG) emissions. The Netherlands has set an ambitious target to reduce GHG emissions by 95% by 2050 compared to the 1990 baseline. Several factors, such as low retrofitting rates, lead to uncertainties in achieving these targets. In the residential sector, the energy retrofit rate of the owner-occupied homes is low. Homeowners encounter different types of barriers when deciding to make energy retrofits. The purpose of this study is to examine the discrepancy between current policy and the actual needs of homeowners in making energy retrofits. We used semi-structured interviews and focus group meetings with experts from the largest cities in the Netherlands as the data collection methods. We identified the discrepancy between current policy and the actual needs of homeowners as follows: (a) less attention to the right message and the right messenger. Policymakers cannot motivate the households using the word sustainability. Policymakers can convince homeowners to make energy retrofits through the improvement in quality of life, the expected cost savings, and the integration of energy retrofits into the maintenance

of the home (message effect). Moreover, the trustworthiness and familiarity of the energy ambassador with the households are the main characteristics of these ambassadors (messenger effect). (b) the lack of integrated financial, informational, and technical support. The main identified transaction cost barriers (non-monetary costs) are difficulties to inspire homeowners to carry out energy retrofits, lack of knowledge on how to start the energy retrofits, many steps in carrying out energy retrofits of old houses. More importantly, there is a lack of an active and accessible party in the market to reduce the financial, technical, and informational barriers.

KEYWORDS Energy retrofit; Homeowners; Decision-making; Behavioural factors; Transaction cost barriers; Local authorities

6.1 Introduction

The building sector accounts for a significant 25% of global greenhouse gas (GHG) emissions. The United Nations has announced a global action to reduce GHG emissions and in the Paris Climate Agreement 200 countries agreed to limit global warming to no more than 2°C above pre-industrial levels. The Netherlands has set a target to stop using natural gas for heating and cooking by 2050. The majority of homes in the Netherlands are owner-occupied. The proportion of newly built homes is also very low. Considering these two factors, renovating owner-occupied homes can contribute significantly to achieving the energy efficiency targets in this country [112, 113].

The Netherlands, following the European Commission's policy, focuses on neighbourhood or district approaches [85]. In these approaches, local authorities play a very important role, for example by providing financial support, communicating with homeowners about all kinds of collective solutions such as district heating, and offering all kinds of collective, cost-efficient and sustainable retrofits for specific buildings and households [349]. In implementing these approaches, the local authorities also face many challenges. For example, in one of the cases, the municipality provides the whole package of technical and financial support. However, in the end, some homeowner associations did not participate in the programs. As a result, other factors may hinder the adoption of the energy efficiency technologies offered by the communities. This and many other examples illustrate that the energy transition is not a technical transformation, but primarily a social one [200]. For successful implementation of the energy transition, municipalities need to figure out how to change household behaviour by identifying the key motivations and barriers to adoption of sustainable retrofits.

The behavioural factors and the transaction cost barriers are mentioned as the most important factors influencing the homeowners' decisions to make energy retrofits using the previous studies [112, 113, 315, 480]. Behavioural factors can be divided into contextual (e.g., building characteristics), motivational (e.g., comfort improvement), and personal (e.g., awareness of energy use) factors [478, 480]. Transaction costs refer to any hidden costs incurred by a transaction with an external source, such as the complexity of processing public information [88, 313]. However, few studies have examined the impact of behavioural factors and transaction cost barriers on the individual homeowner's decision to make energy retrofits. This study aims to fill the gap in the literature by examining behavioural factors and transaction cost barriers for individual homeowners.

This study used a variety of methods, including the literature review, semi-structured interviews, and focus group sessions. First, twelve semi-structured interviews are conducted to assess the barriers that have been addressed by the energy efficiency programs at the city levels. These are conducted with the experts from the cities of the Hague, Amsterdam and Rotterdam. The main findings from the semi-structured interviews helped us to identify the initial identified lists of factors influencing behaviours and transaction cost barriers. Afterwards, two focus group sessions (eight and six experts, respectively) were conducted to evaluate the current practices and potential misalignment with the main identified factors and homeowners' actual needs in the Netherlands. The main research question is "What are the potential mismatches between current policy and homeowners' actual needs?"

6.2 Review of current policies and initiatives across different countries

6.2.1 The role of local authorities and public-private initiatives in reducing the obstacles of energy retrofits

In European legislation, the role of local authorities becomes more important and they can implement national policy in these countries. Research indicates the new role of local authorities and the degree of involvement in promoting energy retrofits. Cooperation with other communities, such as different neighbourhoods and applying a partnership approach are the main features of innovative approaches by local authorities [186, 251]. Local authorities use their financial sources, technical assistance and information to facilitate the process of energy retrofitting in their regions. The provision of these sources depends heavily on the capacity of the local authorities, e.g. a province or a municipality. The local government performs as a booster and facilitate connecting essential parties in the energy transition [254]. Vringer et al., [468] investigate the capacity of Dutch municipalities to meet energy targets. The results show that the effective design and implementation of policy instruments vary widely across Dutch municipalities.

Municipalities provide services through various programmes and initiatives within the region. The information provision is one of main services provided by local authorities. For example, if homeowners are interested in an energy retrofit, experts from the municipality perform an energy scan of the building as part of the Energy Scan programme in The Hague. After the home scan, a report is prepared that includes information about the types of energy-efficient measures that need to be installed in the home. An external company also presents the available options for energy-saving measures in the building. During the implementation of this programme, the target group for this programme has a positive attitude towards energy retrofits. They are currently in the early stages of the decision making process. Experts from the municipality mentioned two groups of households. The well-motivated group is proceeding with implementation. The second group does not know how and where to start [103]. This programme does not yet take into account the barriers in the implementation phase. For example, owners of older buildings have many steps to follow. Therefore, homeowners must turn to other programmes for technical, informational, and financial assistance, which delays the entire energy retrofit process.

Local authorities also offer financial support to homeowners from national and local funds. Despite the huge financial support, homeowners still emphasise the lack of subsidies/loans as one of the main barriers. This barrier may be related to other barriers such as the complexity of applying for loans/grants, lack of awareness among homeowners about the availability of financial support [112, 478]. In addition, during the financing process, homeowners are uncertain about financial advice and how much money they will need for an energy retrofit. For example, the Homeowner Grant Programme observed that it takes a long time to receive financial assistance [159]. Homeowners get contradictory information from different financial advisors. They ask municipalities about the reliability of these advisors. However, the municipality cannot provide this information so as not to advertise the services of a particular company.

Local authorities also assist homeowners with the technical aspects of energy retrofits. They usually hire an external party to advise on technical aspects. For example, in one city in the Netherlands, the municipality works closely with an organisation that provides information about reliable professionals or contractors in the area. The Dutch municipalities also offer technical assistance via one-stop shops/pop-up stores [160].

Outside the EU, local authorities also contribute to energy retrofits. In China, the local government has to provide knowledge and information on energy retrofitting, and the Chinese government acts as the main investor in energy retrofitting [219]. de Feijter et al. [90] conclude that active involvement among households and social intermediaries are essential to realise sustainable retrofit practices in both Chinese and Dutch contexts. In the UK, community-led retrofit has proven to be an effective approach for a range of stakeholders. Community-led retrofit integrates the action network and aims to scale up energy retrofit activities by reformulating them at the community level rather than at the household level [233]. It contributes to engage households in energy retrofits, provide financial support to residents, and develop the local supply chain for energy efficient technologies. This approach can also mitigate the lack of trust between contractors and households and the lack of reliable information for households. However, the UK government needs to extend financial and regulatory support to expand community-led retrofit [233, 362]. In the US, community energy is gaining increasing attention. It refers to when the communities make decision to participate in energy-related activities for multiple reasons. The benefits of community energy include financial benefits, increasing confidence in energy retrofits, and empowering communities. On the other hand, the identified barriers are the lack of supportive regulations and incentives, lack of particular form of engagement with particular policy requirements [67].

Section 2.1.2. explains in detail the role of intermediaries such as these stores in accelerating the energy retrofit of houses.

Messages and messenger effects in promoting energy retrofits in the owner-occupied sector

To encourage policymakers to develop strategies that promote more energy-conscious lifestyles that significantly reduce carbon emissions, a thorough understanding of the factors that influence household energy behaviour and investment decisions is needed. Therefore, to maximise their impact, energy conservation interventions need to reflect the heterogeneity of households and dwelling characteristics and remain sensitive to context-specific factors [488]. Households rarely renovate their houses to make them more sustainable, and the main reasons are usually to save money, improve comfort or provide necessary maintenance for the buildings [21, 167, 247]. Raising households' awareness of the benefits of energy retrofits can encourage them to continue the process of energy retrofitting. Policy makers can use various motivating factors to increase the number of energy retrofits in households. Cost savings, lower energy bills, and increased home value are the most common reasons for undertaking energy retrofits. Improving comfort and quality of life and maintaining the home in good condition are the significant non-economic benefits of energy retrofits [9, 342, 480].

In addition, social and environmental psychologists have examined a range of behavioural evidence to improve the effectiveness of energy policy. Their main findings suggest the use of descriptive social norms and commitment. Descriptive social norms can be used to change behaviours by informing how most other people behave and when they have the characteristics of being closest to people or providing socially comparable feedback. In addition, engagement should preferably be effortful, voluntary, and active. Self-commitment can be reinforced by setting a goal, placing reminders about it, and combining it with a descriptive social norm [17, 423].

Reactions to information received depend heavily on the source of the information. The messenger effect refers to the identity of a person delivering a message and how people react to that person's message. People are strongly influenced by the perceived authority of the messenger. In addition, people are more likely to respond to information that comes from experts [97]. The messenger effect also has a strong interpersonal dimension. The effectiveness of the message increases when people are familiar or friends with the messenger, [99] for example. Social identity theory explains that commonality or shared identity with the messenger affects the effectiveness of the message. According to this theory, people perceive the world around them within and outside their groups, and these perceptions can strongly influence behaviour. Indeed, reactions to messages depend on whether members of the in-group or the out-group delivered the messages, even when people are criticised by them [201, 430].

The person delivering the messages should be knowledgeable and trustworthy to achieve the desired results. In a study by Schultz and Fielding [399], participants are more likely to be influenced by the message to use recycled drinking water if they believe the message comes from an expert who lives in the same region than from an unknown scientist. Tajfel et al. [430] conclude that belonging to a group, e.g., based on gender, ethnicity, nationality, or even neighbourhood, can influence behaviour and promote adherence to the social norms of people in the group. In a study conducted in the United States [86], households that had higher energy consumption significantly changed their behaviour based on a message from a credible source, i.e., the chairman of the New York Public Service. The use of neighbourhood or building block leaders can increase the success rate of promoting energy efficiency in residential areas [6]. This is because people who share their identity are more likely to be trusted and more effective at changing the behaviour of those around them.

In another study conducted by UK department of energy and climate change [92], the impact of advice and information on using thermostat by a trusted source of boiler engineer was investigated for vulnerable households. The results indicated that the information provision did not reduce the energy consumption of the households, as not all households perceive the engineers as a trusted source. In addition, the personality of the engineer or the friendly behaviours had a significant impact on the willingness of participants to accept the advice. Another issue is the lack of public trust in government institutions. In some countries, residents' lack of trust in government leads to inadequate communication about certain issues, such as climate change. Differences in trust also depend on the group of households. For example, low-income households have less trust in government than higher-income households. In another report by UK department of energy and climate change, the messages communicated by peers tend to be perceive more pleasantly by households compared to the interventions by policy makers or utility companies and can lead to higher energy saving.

The role of intermediaries in reducing the transaction cost barriers

Transaction costs arise from interaction with external parties and refer to any hidden costs during the retrofit process. A new agency could be established to remove certain obstacles, i.e. transaction costs, and accelerate sustainable retrofits. This agency can be a formal institution or an expert in the field of sustainable retrofit. The agency can provide financial, informational and technical support that is essential for the implementation of energy efficient retrofit. There are two main reasons for lowering the cost of services to access energy efficient retrofits. Intermediaries have the advantage of economies of scale, scope and specialisation and have greater technical, commercial, legal and business expertise compared to homeowners. They often have access to finance, equipment and energy commodities at lower prices. Second, the process of outsourcing consists of market competition that leads intermediaries to bid close to the marginal costs of energy retrofit providers. Customers may face inefficiencies and monopolistic prices. Households face transaction costs, including search costs, negotiation costs, and opportunity costs. Contracting with an intermediary makes sense if the cost of savings from using intermediaries is higher than the transaction costs [339].

Homeowners may have to invest a lot of time and effort to find the funding sources or the subsidy programmes and loans offered by the agencies. In addition, for example, households may encounter issues finding reliable professionals and contractors. Informational assistance may include, for example, identifying the appropriate types of energy retrofits for the homes. The households should compare the expected costs and future benefits of energy efficient technologies to select the appropriate ones. However, households may select less energy efficient technologies compared to a professional intermediary due to incomplete information and transaction cost barriers [202].

Intermediaries significantly influence the decision-making process at different stages of energy retrofits. Households mainly seek advice from one or a few intermediaries and select intermediaries in the early stages of energy retrofits. Very few homeowners sought advice from an energy consultant. According to this study (Arning et al. 2020), the selection of an intermediary determines the results and the quality of the energy retrofit, as the intermediary has a great influence on the selection of energy saving measures. Moreover, personal experience or personal recommendations determine the choice of intermediaries rather than professional qualification criteria. The authors recommend raising homeowners' awareness of the selection of intermediaries based on qualifications and certifications in energy retrofits [21].

A professional intermediary can facilitate the process of retrofit by removing the barriers mentioned above. Currently, there are initiatives in European countries. These initiatives can operate independently or be part of government agencies. One-stop shops or pop-up shops, for example, raise awareness among households about energy retrofits. These types of shops also offer a whole package of financial, technical and informational support to homeowners. 63 one-stop-shops are identified in the EU, and these shops operate 100,000 projects per year in the European market. On-stop shops know the local market, support the building owners during the whole process, and enhance the average energy performance using a holistic approach. Despite the strong potential of one-stop-shop, barriers exist for starting these business, such as uncertainty about the customer base, uncertainty about the level of energy savings [53].

In the Netherlands, homeowners can contact energy desks set up in 200 communities to get information and find customised solutions to improve the energy efficiency and comfort of their homes. The Energy Desks (in Dutch: regionaalenergieloket) are the result of collaboration between communities, contractors and installers. Therefore, technical support for energy retrofit is also accessible. This organisation works with 50 municipalities in the Netherlands and facilitates decision-making by citizens regarding energy efficient measures, subsidies and techniques. In the Netherlands, Reimarkt is a professional organisation that works closely with municipalities, local initiatives, residents, housing associations and suppliers. Reimarkt offers free energy scans, free advice and low-cost packages for energy retrofits. In south-east Amsterdam, the CoForce Foundation oversees the process of sustainable retrofit and facilitates the process by, for example, accessing the information. Energy coaches and energy ambassadors (who live in the same area as the residents) also play an important role in the project. The latter helps each individual by visiting the homes. The former is a highly qualified professional who advocates sustainability and advises on a higher level of strategic planning, e.g. on the financing of the project [56, 292, 359].

6.3 Research methods

6.3.1 Semi-structured interviews

In semi-structured interviews, there are lists of questions which are asked in all interviews and based on the answers of the interviewees some other additional (more specific) questions are asked. We aimed to collect information about the barriers and opportunities of sustainable retrofits in the owner-occupied sector by interviewing the experts and practitioners in the field of energy and buildings. We mainly target the experts who deal with promoting the sustainable retrofit in the owner-occupied sector. Questions regarding the upscaling potential of these schemes, i.e. the industry structure and institutional barriers are also included. Twelve semi-structured interviews are conducted. These interviews took approximately 1-1.30 hours. All interviews are conducted online due to COVID-19 crisis.

The interviews consist of three parts: (1) general information about the interviewees; (2) aims and the target groups of the initiatives at the municipalities, (3) barriers of sustainable retrofits (4) what should be the message in promoting the sustainable retrofits? and who should transfer this message? The interviewees are the experts that are involved in the implementation of the project regarding the promotion of sustainable retrofits in the owner-occupied sector. The interviewees act in different functions within the project including project leader, communicator with the customers, policy expert, energy coach and energy commissioners. The information from one interview may lead to the additional questions in the next round of the interviews.

The Dutch municipalities offer the energy efficiency programs for different groups of people. Some of the projects specifically address the individual homeowners, such as energy scan offered by the Hague. The other projects target for example the homeowner associations, such as homeowner association funding offered by the Hague and national government. In each case, the following factors are included: (a) the main aim of the case project, (b) the target groups and stages of sustainable retrofit, (c) the addressed barriers, and (d) solutions of the municipalities to address the barriers.

6.3.2 Focus group

The focus groups aim to investigate the obstacles and opportunities for individual and collective actions towards sustainable retrofits. The barriers and opportunities for the individual homeowners are investigated from the perspectives of policy makers and practitioners. Two focus groups are designed and conducted to reach the aim of the focus groups. Eight and six experts participate in the first and second focus group sessions, respectively.

1 The decision-making processes

There are two types of decision-making processes for sustainable retrofit: individual and collective decision-making processes. The differences and similarities are investigated in the first focus group. Individual homeowners encounter many difficulties in conducting the sustainable retrofit, even if they are interested to be involved in sustainable retrofit. In addition, municipalities offer technical, financial, and informational supports specifically designed for homeowners' association and social housing corporation. However, the number of these associations who join the energy efficiency programs are very low. In some cases, a building may have both homeowners' association and social housing corporation. Then, the problem become more complicated for joining the energy efficiency programs. These two associations have different target groups and legal framework which need to be considered, as well. For example, in the municipality of the Hague, it has been seen that even by providing the complete packages of financial and technical supports from the municipalities, homeowners' associations and social housing corporations failed to get the most votes of all the tenants or homeowners in conducting retrofits or sustainable retrofit. The main questions to you are:

- How to get the homeowners interested in sustainable retrofit?
- How to engage the homeowners through the whole journey?

1 **Promoting sustainable retrofits by right message and messenger effects**

Homeowners have different reasons to be involved in sustainable retrofits. From the previous studies and interviews, people conduct the sustainable retrofit for other reasons, such as improving the comfort of the buildings. Municipal representative found it very important to address the main drivers of homeowners for sustainable retrofit. The question to you is:

- What other observations have you seen in your current practices? We also test this hypothesis that the government and the municipalities might not be the right communicator with homeowners for sustainable retrofits. In the current practices, we have seen other effective communicators, such as energy commissioners, a trusted neighbour, etc. The question to you is:
- Who do you think would be the trusted ambassador? Why?

2 **Setting up a new agency**

From the current practices, it has been observed that the municipalities hire an external party to give the neutral advice on sustainable retrofit. We would like to explore:

- What are the other examples in your current practices?
- What should be the type of agency (an agency as part of the municipality, NGO, independent agency)?
- What should be the contributions of the agency?

6.4 Results

The previous research identified the main barriers towards energy retrofits. This section presents the results of the semi-structured interviews and focus group sessions.

6.4.1 Which obstacles are the most important ones from the project leader of the municipality and practitioner perspectives?

Before explaining the results, it is important to know that policy makers need to consider different groups of people. These people have different characteristics, e.g. income, age, education and knowledge about energy retrofits. For example, households with higher incomes might be less concerned about the cost of energy retrofits or might be less concerned about the energy retrofit expenses. For this group of households, the provision of information by public authorities can speed up the process of energy retrofitting. In summary, the barriers identified in the focus group sessions are mainly associated with average household groups. This statement is also mentioned by the focus group participants.

The results of *the two focus group sessions* on the main identified barriers were similar. Both expert groups identified (a) a lot of time and effort to find reliable information, (b) expensive energy saving measures, and (c) the complexity of implementing energy saving measures, e.g. due to structural reasons or living in an old building, as the most important barriers. The programmes initiated by the municipalities mainly aim at removing these barriers for individual homeowners.

The experts indicated that finding reliable information, e.g. reliable technical advice, is one of the main barriers to energy retrofits and requires a lot of time and effort. The types of information can be mainly divided into information on the reliability of contractors, information on the reliability of financial advisor, and information on grants and loans (*semi-structured interview*). During t*he first focus group meeting*, an expert of the municipality explained that it is always a big challenge for homeowners to figure out the most appropriate types of energy retrofit for their home. The energy advisor of the municipality provides technical information on the possible energy retrofit measures for the buildings. The final decision on the most appropriate energy retrofit requires more specific technical advice for the buildings, which also provides information on the feasibility of the energy retrofit and the phases that the homeowners need to follow. Homeowners usually inquire about the reliability of the financial advisor and the technical advisor of the municipality. However, the municipality cannot provide this information. Homeowners are provided with all kinds of services, however, at the end, the households ask about the reliability of the parties involved in the process.

In some municipalities, an outside party provides unbiased advice about the reliability of professional contractors. In addition, homeowners interested in energy retrofits regularly ask for assistance in applying for grants/loans, even though there are numerous programmes and online platforms for grants, loans, and subsidies (semi-structured interview). When homeowners found out where they could access funding sources. They also wanted to know if these funding sources were still available long before they made their final decision. All kinds of uncertainties also hinder the process, such as the likelihood of getting the grants/loans/grants, the impact of changes in political parties on financial support for energy retrofits, and the right timing for the investment. One expert said that people ask these questions, “Is there any money left at the time I want to apply?, what happens when the elections happen?, People also find it difficult to choose between a forest of options, but they also have the question of whether it’s the right time to invest.” (*Second focus group session*)

The second main obstacle was the high cost of energy retrofits. According to the experts' observations, people prefer to start with small energy retrofits and avoid investing high capital costs in energy retrofits due to other necessary living expenses. Expert A said that "no matter how well people understand the benefits of sustainable retrofits, no matter how enthusiastic they are. Most people who stop or take on retrofits make the decision with their wallets in hand." (*First focus group session*)

The grant programme's project manager explained that owners have to incur various types of costs to their buildings, such as painting the walls. Individual owners may not see the value in paying additional costs for energy retrofits with uncertain benefits. A project manager for the grant programme emphasised that the cost of energy retrofits is the most important factor in the final decision, regardless of the homeowner's willingness and interest in energy retrofits. The energy retrofits must also provide a short-term benefit. Otherwise, homeowners will not invest in something that will not pay for itself within five years, considering other expenses and financial investments (*First focus group session*).

Even people who are interested and motivated to conduct the energy retrofits, they perceive it as a complex process. They ask to make the process carefree for the households both technically and financially. The households expect step-by-step hassle free energy retrofits process provided by the public authorities (*the semi-structured interview*). Based on an expert opinion, people at the decision stage asked the questions of What does it cost?, how much they can save?, How much money they can borrow?, what can they do? and how they can do it? how can they hire a contractor?. The people mainly look for de-hassling the process of energy retrofits (*First focus group session*).

A new transaction cost barriers is identified during the *second focus group session* which has not been addressed before: homeowners uncertainties regarding the policies, such as removing the natural gas from the heating system. Homeowners must recognise the need and urgency for energy retrofits in order to take action. Most people are reluctant to take action until they are less uncertain and those actions become the social norm. For example, homeowners need to know exactly how to remove natural gas from their heating systems. Currently, residents are very unsure about removing natural gas, so it is difficult to motivate them to begin the process. There could be an explanation for this, such as miscommunication by officials regarding energy retrofit programmes and public-private initiatives. For example, the city government promises planning for the elimination of natural gas in the heating system. However, the planning for individual districts is not entirely clear.

From the *focus group sessions*, it appears that policy makers are facilitating homeowners' entry into the decision-making phase. Barriers in the implementation phase, such as homeowners' knowledge and skills regarding energy retrofits and clutter and nuisance during the works, are not addressed in current municipal practice. This is to be expected as the responsibility for this phase rests entirely on the shoulders of homeowners. However, policy makers need to reconsider how to reduce the perceived nuisance factor during the execution phase of energy retrofits.

6.4.2 How the policy makers and public-private initiatives edit the language to communicate the promotion of sustainable retrofits?

Homeowners may be at different stages of energy retrofits. Some of them are not even thinking about energy retrofits yet. Some are thinking about different types of energy retrofits, and the others are already doing energy retrofits. They have different characteristics and needs for their homes (*the semi-structured interview*). In the *focus group session*, the question was asked what messages the experts use to motivate households to carry out energy retrofits.

The general answer to this question was that it really depends on the context and the intermediary delivering these messages. For example, improving quality of life is important for people who can repay the cost of energy retrofits. Similarly, the availability of financial support from national and local authorities may be more influential for people who cannot afford the cost.

A combination of messages is used to motivate households to undertake energy retrofits. For example, one expert mentioned that for promoting solar panel, "We tell people it's good for the environment and good for your wallet." Another expert said that "an environmentally friendly group of households will always find their way and they will also reach out to the city government or other parties, and the city government will help them. Also groups of people asking for help in maintaining the buildings. We combine the maintenance immediately with appropriate energy retrofits. For example, by offering financial incentives that 50% must be invested in maintenance and the other 50% in energy retrofits." (*the semi-structured interview and first focus group sessio*n)

We should note that the message depends on the target audience and that a combination of messages is usually used to promote sustainability. From *the semi-structured interview and focus group sessions*, the most important messages are described below:

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- **Improving the quality of life**

  In almost all programmes, experts mentioned that using the word sustainability does not lead to the implementation of energy retrofits. Most people are motivated to renovate their homes if they feel it is necessary or perceive an improvement in their quality of life (*the semi-structured interview*). For example, in a programme implemented by one of the municipalities improving comfort by insulating the floor was the most attractive message, as people in this region struggle with cold floors (*the second focus group session*).

- **Essential maintenance of the house**

  The necessary maintenance of the building was mentioned in all programmes (*semi-structured interview*) as well as in the *focus group meetings* as the most important moment to motivate households to participate in energy retrofits. For example, if the roof needs to be renewed, this maintenance can be combined with the insulation of the roof. The municipalities offer subsidies and financial options that oblige to use a part of the budget for energy retrofit and the rest for maintenance of the building. This type of incentive seems to be very effective for the implementation of energy retrofits (*the semi-structured interview*).

  In one of the regions in the southeast of Amsterdam, the households own very old buildings that are in great need of retrofit. Due to lack of budget, It would be difficult to ask people to bear the extra costs of energy retrofits. However, if the expert can convince people that they will have a more comfortable home in the future, they may consider energy retrofit (*the semi-structured interview*).

- **Expected cost saving**

  If people have a clear idea of the expected cost savings from an energy retrofit, they will certainly consider it. For example, owners of buildings with the lowest energy labels, such as F and G, have to pay hundreds of euros per month for energy costs. There were cases in the South East of Amsterdam where the owners had to pay 4000 euros per year for energy costs. The Energy Ambassador explained to the building owners the benefits of energy retrofit in terms of cost savings per year. In this way, the owner was convinced to carry out the energy refurbishments (*the semi-structured interview*).

6.4.3 Who should deliver the message and create a trustworthy channel of communication?

The benefits of energy retrofits must be communicated in the early stages. In addition to the type of message, it is also important who delivers the message and creates a trusted communication channel to households. Ambassadors for sustainable retrofits can be an expert hired by the municipality/homeowners or an independent expert, a person trusted by tenants and residents, such as a trusted neighbour, an energy retrofitter interested in sustainability, a front runner in the adopting energy retrofits, and a volunteer in promoting sustainable retrofits (*the semi-structured interview and the focus group session*).

According to *the semi-structured interviews* and the *focus group sessions*, the first moment of communication is very important to get homeowners interested and engaged in the energy retrofit programmes. The municipality has recognised that official communication through letters and community ambassadors does not have an effective impact on households' energy retrofit decisions. In *the second focus group session*, an expert mentioned that residents are reluctant to respond to letters from the authorities. For example, the municipality sent a survey to five thousand households in one neighbourhood. Only 250 households responded to the survey. One expert said that the reason could be that people receive so many letters to pay their bills that they are unwilling to respond to more letters.

In another experiment, the energy expert went to a neighbourhood and talked to people. In the end, people actually acted on their conversations with the energy expert. Also, another expert mentioned, the lack of knowledge of the Dutch language was an important obstacle. There are many people living in the Netherlands who do not speak Dutch. These groups may not understand the technical and financial information provided through various communication channels, such as social media. Therefore, it is important to make the information as clear as possible and also very interesting for all groups of residents. The question arises as to who should deliver the message to the homeowners to arouse their interest in energy retrofits (*the second focus group session*).

It emerges from *the focus group meetings* that a building ambassador can also help to motivate people to make energy-efficient retrofits. Government, local authority programme managers or housing associations are seen as third parties. One expert mentioned that "Households may feel pressured by these bodies and resist the measures they propose to improve the sustainability of buildings. If a household is interested in energy retrofits, it would be much easier to motivate other households through this household than through external third parties."

One expert mentioned in *the first focus group session*, “I do not know if it should be exactly a neighbour or the caretaker, but someone you trust and have some relationship with. In most cases I know, it’s not an expert who suddenly shows up on your doorstep and you do not know them, and often it’s not the municipal expert” Another expert acknowledged, “If the homeowners are already interested in energy retrofit and have gone through the consideration phase, an expert hired by the homeowners can effectively communicate the benefits and convince the homeowners to do the energy retrofit. For example, if someone wants to install a heat pump, the first action is to find a reliable expert who can provide them with information and services to install the heat pump specifically for their building.” (*the second focus group session*)

In the southeast of Amsterdam it is more expensive to rent a house than to buy one with a mortgage from the banks, and in this region, the lowest income group usually own a house. These homeowners perceive the condominium associations as their landlords. Any expenses that the associations demand are seen by them as additional costs, and they may resist these costs. Shared events and creating local networks, such as cooking/playing sports, can be a safe environment to talk to homeowners about sustainability. The energy ambassador can combine these events into activities to put sustainability into practise. In this case, an event using visualisations or using different languages to communicate the benefits of a more comfortable home equipped with energy retrofits can be an effective way of communication (the semi-structured interview and the second focus group session).

In the focus group sessions, the experts mentioned that “people do not even think about energy retrofits. Moreover, the majority waits for one person to implement the measure first, and if the results are satisfactory, they may follow that person.” The environmentally conscious group of households could be an example of the frontrunners, as this group is actively looking for ways to live more sustainably. After this stage, if the homeowners decide to undertake energy retrofits, they may contact an expert they have hired themselves or who has been hired by the municipality for information or other services, such as financial support, to continue the process. So it also depends on how far the energy retrofit has progressed. An expert hired by the homeowners can also effectively communicate the benefits and convince the homeowners to undertake the energy retrofit. In addition, experts hired by local governments often offer free services. So in this respect, homeowners can also benefit from these services.

6.4.4 How can a new intermediary help to remove the main obstacles identified? Is such an intermediary necessary?

This subsection describes the results of the semi-structured interviews and focus group sessions to assess the involvement of third parties in removing barriers and providing information, financial, and technical assistance to homeowners. The agency/intermediary is not an organisation, it can be a digital platform, an online website, an independent energy expert. First, the examples of case projects are explained below. The role of an agency in removing barriers was also discussed in the focus group sessions. The results are listed below:

- The City of Rotterdam is already working with an agency to remove the financial and technical obstacles, the “Woonwijzerwinkel”. First, homeowners must hire an energy consultant. Then, they can find providers of energy retrofitting services through the “Woonwijzerwinkel”. However, the municipality still faces challenges when it comes to answering homeowners’ questions: “Is this organisation a reliable, independent party?”, “Will this organisation remain independent in the future?”. The municipality has asked “Woonwijzerwinkel” to clarify the process, such as the selection of reliable contractors, to overcome the challenges. As another solution, the municipality has set up sustainability shops in some Rotterdam neighbourhoods (*the second focus group session)*.

- The City of The Hague has set up a retrofit store called “Love your home” where citizens can simply drop in and ask their questions about the different types of retrofits, including energy retrofits. This store works in collaboration with other experts in the field of retrofits and can help residents to make an informed choice, such as the cost of energy retrofit, collective purchasing by homeowner’s association. The city’s ambassadors are familiar with the homeowner’s journey and the various obstacles they face. In the past, the municipality of The Hague has also recommended that households use the services of the “Woonwijzerwinkel”. This shopping store offers different preferences in terms of materials and brands. The shopping store was also useful for the municipality, as the municipality did not want to give commercial advice to companies offering different types of energy retrofit services. However, the municipality ended the cooperation with this shopping centre, as this company no longer offers services in the region of The Hague (the semi-structured interview and focus group sessions).

- Milieu Centraal has developed an online platform. This platform provides various options for building energy retrofits based on the building characteristics that homeowners enter into the online platform. The platform provides information on the cost and energy savings of energy retrofits. However, the expert from Milieu Centraal stressed that personal contact, for example through a volunteer energy advisor, is very important so that people can be sure about the different energy retrofit options. Currently all services are offered separately and it can be immensely helpful to have a party to advise on all these stages of energy refurbishment (*the semi-structured interview*).

- The CoForce Foundation was established to support the energy transition objective of the city of Amsterdam to have gas-free neighbourhoods in 2040. CoForce searches for and stimulates energy transition initiatives of residents and businesses in the Amsterdam Southeast district. The Foundation connects ideas, knowledge and manpower. Good ideas are funded and supported by so called energy commissioners who are professionals in the field and part of the professionals network of CoForce. All of them live or work in Amsterdam Southeast. Examples are projects to install solar panels and energy saving projects in various neighbourhoods. Another aim of the Foundation is to stimulate employment in the field of energy transition. The current volume of initiated projects shows the added value of CoForce: bottom-up, residents in the lead, easy startup funding (*the semi-structured interview and the second focus group session*).

- The Neighbourhood Power Foundation, called Buurkracht in Dutch, finds active residents and initiators in the neighbourhood who want to work with their neighbours to make the neighbourhood more sustainable. This foundation follows various approaches. For example, short-term projects for ten weeks where a single energy retrofit, such as a photo-voltaic system or insulation, is done. A neighbourhood-based approach, where residents are helped to create a plan to make their neighbourhood natural gas free in the longer term (10-15 years). The clients of this foundation are municipalities and sometimes provinces (*the second focus group session*).

6.5 Discussion

This paper focused primarily on the role of local government and public-private initiatives, message and the messenger effects in promoting sustainability in the housing sector, and the establishment of a new agency to implement energy retrofits. A list of barriers was presented in the focus group sessions and participants commented on the importance and actions needed to address these barriers. Examples of policies and public-private initiatives were identified through literature review, semi-structured interviews and focus groups with policy makers and practitioners. Several research questions were posed as part of this paper and are discussed below.

6.5.1 Identified barriers by policy makers and practitioners

Limited/no subsidies, cost of energy retrofits, time and effort to find subsidies and loans, reliable professionals are mentioned as the main barriers to energy retrofits from the previous studies [112, 113]. The data from the focus group meetings showed that municipal project managers are aware of the main transaction cost barriers, such as the complexity of processing applications to access public funds. The main barriers confirmed by policy makers and practitioners were (a) a lot of time and effort to find reliable information, (b) expensive energy saving measures and (c) the complexity of implementing energy saving measures, e.g. due to structural reasons or living in an old building. In addition to the barriers from the previous study, project managers and practitioners also mentioned other important transaction cost barriers, such as homeowners' uncertainty about national policies, e.g., phasing out natural gas heating, and misunderstandings due to language barriers. The reasons we were unable to identify these barriers are the lack of data and the limitation of available datasets.

6.5.2 Message and messenger effects in promoting energy retrofit

From previous research, cost savings, improving comfort, the maintenance state of the house are the most common reasons for implementing energy retrofits. Improving comfort and quality of life and keeping the home in good condition are the main non-economic benefits of energy retrofits [9, 342, 480]. Project managers and practitioners also mentioned that the word sustainability does not convince homeowners to undertake energy retrofits. The improvement in quality of life, expected cost savings, and integration of energy retrofits with basic home maintenance are the most important messages that convince individual homeowners to make the energy retrofits. Most people are motivated to renovate their homes if they see the retrofit as necessary or see it as improving their quality of life. For example, in a programme implemented by one of the municipalities improving comfort by insulating the floor was the most appealing message, as people in this region struggle with cold floors. In addition, the social and environmental psychologists have examined a range of behavioural evidence to improve the effectiveness of energy policy. They suggested using the descriptive social norms and commitment for motivating individuals to conduct an action [17, 423]. The examples of such policy instruments were not mentioned by the experts in the focus group sessions.

The messenger effect refers to the identity of a person delivering a message and how people respond to that person's message. People are strongly influenced by the messenger's perceived authority, commonality or shared identity with the messenger, and the messenger's knowledge and trustworthiness about the problem [97, 201, 430]. From the semi-structured interviews and focus group sessions, it appears that the perceived authority of messengers is not effective. Local authority or housing association programme managers are seen as third parties. Households may feel pressured by these authorities and resist the measures they propose to improve building sustainability. In addition, the project leaders mentioned that letters and surveys from government agencies are ineffective means of promoting energy retrofits compared to face-to-face discussions at various workshops. On the other hand, the trustworthiness and shared identity of the ambassadors are considered more important.

6.5.3 Facilitating the energy retrofits by a new agency

According to the literature, Nolden, et al., [21]; Arning et al. [339], intermediaries usually have the advantage of economies of scale, scope and specialisation and have greater technical, commercial, legal and managerial expertise compared to homeowners. On the other hand, households may face inefficiencies and monopolistic prices. In addition, households need to consider that hiring an intermediary is beneficial if the cost savings of using an intermediary are higher than the transaction costs. The quality of the retrofit depends on the intermediary, as the intermediary has a great influence on the choice of energy saving measures. Moreover, personal experience or personal recommendations are decisive for the choice of the intermediary and not the professional qualification criteria.

Many examples of external agencies are given by project managers and practitioners. For example, the municipality of The Hague has set up a retrofit store called "Love your home" where citizens can simply drop in and ask their questions about different types of retrofits, including energy retrofits. This store works with other experts in the field of retrofit and can help residents make an informed decision, such as the cost of energy retrofits, collective purchase by the homeowners association. The experts believe that these agencies are very important to address the financial, technical and information barriers. However, the experts were uncertain whether these agencies should be dependent on the municipalities or independent and they were not aware of specific characteristics of the intermediaries to be accepted and to be reliable by households.

6.6 Conclusions

The aim of this study was to examine current energy policy and public-private initiatives in the Netherlands. It investigated which messages and ambassadors are effective in promoting sustainability. In addition, the main identified barriers to energy retrofits were examined from the perspective of policy makers and practitioners. Finally, the role of a new agency in addressing the financial, technical and informational barriers is explored. The data collection methods are semi-structured interviews and focus group meetings.

Promoting Sustainable Retrofits

The results of this study show that (a) the word sustainability does not persuade homeowners to make energy efficient retrofits. The quality of life improvements, expected cost savings, and integration of energy efficiency retrofits with basic home maintenance may convince individual homeowners to make the energy efficiency retrofits. (b) Municipal project managers have cited letters and surveys from government agencies as ineffective means of promoting energy retrofits. (c) Trustworthiness and familiarity of the energy ambassador with households are the most important attributes to increase the effectiveness of energy programmes or household adoption of energy retrofit by households.

Barriers to sustainable retrofits

Even people who are interested and motivated in energy retrofits consider them to be a complex process. Households want a straightforward process, both technically and financially. Moreover, people expect the authorities to provide this step-by-step process for a hassle-free energy retrofit for households. Based on expert opinions, people asked questions about the cost, energy savings, loans/subsidies, type of energy retrofit, reliable contractors, and facilitation of the energy retrofit process in the decision-making phase.

The data suggest that municipal project managers and practitioners are aware of key transaction cost barriers. The main transaction cost barriers identified in energy retrofit programmes were (a) a lot of time and effort to find reliable information, (b) expensive energy saving measures, and (c) the complexity of implementing energy saving measures, e.g. due to structural reasons or living in an old building. In addition, they reported new transaction cost barriers, such as homeowners' uncertainty about national energy policies, e.g., the elimination of natural gas heating.

Establishing a new agency to address financial, technical, and informational barriers

Many examples of external agencies are cited by project managers and practitioners. Experts believe that these agencies are very important to remove the financial, technical, and informational barriers. Experts were unsure about the characteristics of a new agency, such as whether these agencies should be dependent on the municipalities or independent. Few examples of these types of agencies were presented. Some of them offer the entire technical, informational and financial packages that are essential for implementing energy retrofits. Few of these agencies work independently, such as Buurkracht, a non-profit organisation. The others were initiated by the municipalities, such as "love your house". People have more confidence in the services offered by the municipality. On the other hand, they perceive the advice from the independent party as more neutral.

7 Conclusions

7.1 Highlights in Summary

Retrofitting the residential sector is necessary to reduce energy consumption and achieve the goals of the climate agreement. Among the various sectors, homeowners are fully responsible for the energy retrofitting of their homes. The energy retrofit processes are complex, and homeowners face issues in acquiring financial support, reliable information and expert during the process [112, 393, 478]. To facilitate the processes of energy retrofit for individual homeowners, it is important to understand the factors that influence the decision-making and renovation process. In this way, it is possible to investigate the main determinants of behaviour, the main barriers to energy retrofits, and the incentives to encourage homeowners to take action and facilitate the energy retrofit process. This dissertation aims to assess (1) the main factors influencing behaviour, including psychological factors, during the decision-making process of homeowners in energy retrofits. Behavioural factors mainly explain a range of contextual, motivational and psychological factors influencing the decision making process. The contextual factors include the homeowners and property' characteristics, while the psychological factors contain the personal factors of cognitive awareness and cognitive biases [183, 451, 480], (2) the transaction cost (TC) barriers, the non-monetary costs or hidden costs, during the retrofitting process. The transaction costs means any hidden cost that has not been counted in the cost and has been made due to a transaction with an external party [113, 135, 313, 316]. In addition, policy instruments to promote energy retrofits and to reduce barriers were investigated. The behavioural aspects and transaction cost barriers are among the main factors influencing the individual decision making and renovation processes.

The main research question of the thesis was:
"How to improve the individual decision making and the process of energy retrofitting using the behavioural and transaction cost perspectives?"

The main question has been divided into four key questions, answered in Chapters 2, 3, 4, 5 and 6 respectively:

1 How can the behavioural factors and transaction cost barriers influence the decision-making and renovation processes of homeowners towards energy retrofits?

2 What are the most important factors influencing the behaviour of homeowners during the decision-making process for energy retrofits?
   a Which contextual, motivational, and personal factors significantly determine the homeowners' behaviours towards energy retrofits?
   b Which cognitive biases significantly determine the homeowners' behaviours towards energy retrofits?

3 What are the main transaction cost barriers during the renovation process for the homeowners in the Netherlands?

4 How can the outcomes of this thesis be used to evaluate the potential misalignment of the current policies in promoting energy efficiency renovations in the Dutch owner-occupied sector?

TABLE 7.1 - Summary of Responses to the Research Questions

	Key question	Answers to the research questions
Chapter 2	(1) How can the behavioural factors and transaction cost barriers influence the decision-making and renovation processes of homeowners towards energy retrofits?	- An integrated framework of behavioural factors and transaction cost (TC) barriers to decision making and the process of energy retrofitting is developed. - The behavioural factors are particularly important in the early stages of the energy retrofit. - TC barriers are the second main category of obstacles after the financial barriers. - The time and effort spent in finding information, and the reliability of information and experts were identified significant and important barriers. - The financial barriers may be due to the TC barriers of lack of available information on the subsidies and loans for homeowners.

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TABLE 7.1 - Summary of Responses to the Research Questions

	Key question	Answers to the research questions
Chapter 3	(2) What are the most important factors influencing the behaviour of homeowners during the decision-making process for energy retrofits? (a) Which contextual, motivational and personal factors significantly determine the behaviour of homeowners towards four types of energy retrofits?	- The decision to install double glazing is largely influenced by the characteristics of the building and the household. - Decisions on insulation are highly influenced by the characteristics of the building. - Personal factors of perception of households on energy consumption compared to other households significantly influence the decision to install PV panels. - Building and household characteristics, as well as, personal factors influence the decision to install a sustainable heating system. - Motivational factors significantly influence the decision-making process for different types of energy retrofits.
Chapter 4	(b) Which cognitive biases significantly determine the homeowners' behaviours towards energy retrofits?	- A fundamental investigation into the mathematical modelling of cognitive biases is conducted. - Accounting for cognitive biases significantly improves the prediction of households' actual decisions about energy retrofits. This modelling is more accurate than the model that assumes households make rational decisions. - Loss aversion and risk-seeking behaviours in loss are identified as highly important for energy efficiency investments.
Chapter 5	What are the main transaction cost barriers during the renovation process for the homeowners in the Netherlands?	- Homeowners have different transaction cost barriers to renovations and energy retrofits. - Finding a reliable professional/contractor to perform the work is the main identified TC barrier for exterior renovation. - Information about how to perform the work is the main identified influencing factor in the renovation decision for interior renovations. - For energy retrofits, the main barrier is the difficulty of finding ways to make houses more energy-efficient.
Chapter 6	How can the outcomes of this dissertation be used to evaluate the potential misalignment of the current policies in promoting energy retrofits in the Dutch owner-occupied sector?	- The key transaction cost barriers are the complexity of processing applications to access public funds, homeowner uncertainty about national policy, and the elimination of natural gas heating from the point of view of policymakers. - The word sustainability does not convince homeowners to make energy retrofits. - Households are strongly influenced by the trustworthiness and shared identity of energy ambassadors. - The external agencies are very important to remove the financial, technical and information barriers.

7.2 Key Findings on the behaviour influencing factors and the transaction cost barriers

This dissertation consists of five core chapters, each devoted to a study, and answering the associated research questions. The main behaviour-influencing factors and TC barriers influencing the process of energy retrofitting have been investigated in several studies in this dissertation. Chapter 2 was the first attempt in the literature to develop an integrated framework of behavioural factors and TC barriers for the energy retrofit decision-making process. The next chapters specifically addressed the impact of behavioural factors on different types of energy retrofit insulation, double glazing, solar PV panel, and sustainable heating system (Chapters 3 and 4) and the impact of TCs on different types of renovation and energy retrofit (Chapter 5). Chapter 6 examined the misalignment between the current policy and the homeowners' actual needs .

7.2.1 How can the behavioural aspects and TC barriers influence the decision-making and renovation processes of homeowners during energy retrofits?

A literature review was used to develop an integrated framework of factors that influence behaviour and transaction cost barriers in the decision-making and energy retrofit process. The theoretical framework was validated through statistical and regression analyses.

More powerful insights into homeowner decision-making processes can be achieved by including a range of personal and contextual factors to explain the decision [32, 480, 481]. The factors influencing behaviour are particularly important in the initial phases of energy retrofitting, i.e. in the acquisition of knowledge or the formation of attitudes. As mentioned above, TCs are defined as all indirect, unavoidable costs in a transaction with an external party [80]. TC barriers reduce the effectiveness of policy instruments to promote energy retrofits [313, 316].

The behavioural influencing factors of household and building characteristics are highly identified as important for energy retrofitting. The improvement of the quality of life and the financial benefits are the most important motivating factors. Among the barriers, the results of the statistical and regression analyses show that, first, the cost of energy retrofits and limited/no subsidies were identified as significant and very important barriers. Second, TCs are the second main category of barriers after financial barriers. The time and effort required to find information, the reliability of information and experts, and the complexity of carrying out renovations were the main identified significant and important barriers.

The factors that influence the homeowner behaviours are specifically addressed in two chapters of this thesis. The sub-question 2 was:
(2) What are the most important factors influencing the behaviour of homeowners during the decision-making process for energy retrofits?
The following subsections answered the research question 2.

7.2.2 Which contextual, motivational, and personal factors significantly determine the homeowners' behaviours towards energy retrofits?

Only few studies have comprehensively investigated the factors influencing homeowners' behaviours on different types of energy retrofits [60, 71, 217]. The third chapter examined the impacts of this category of factors on the most common types of energy retrofits in the Netherlands using regression analyses. Homeowners invest in different energy retrofits depending on different factors that influence behaviour. The installation of double glazing is largely related to the year of construction of the house. The decision to install insulation is also largely influenced by the year of construction and the type of building. In addition, the energy label of the houses has a significant influence on the installation of solar panels.

Energy retrofits are mainly implemented in combination with other types of renovations. As might be expected, homeowners install double glazing in combination with repairing or replacing window frames. They also installed PV panels mainly in combination with roof repair/replacement. Homeowners' motivations also differ for each energy retrofit. However, improving comfort and quality of life, improving building maintenance and saving energy costs are the most commonly diagnosed motivating factors among homeowners. These findings remained valid and were confirmed by a very recent report published by Steenbekkers et al. [418].

Personal factors are of great importance for energy retrofits. A combination of building and household characteristics and personal factors of consciously reducing gas consumption were key to the decision to install a more energy efficient heating system. While none of the personal factors had a significant impact on the decision to install double glazing, the installation of PV panels was strongly influenced by the personal factor of household perceptions of energy consumption compared to others.

7.2.3 Which cognitive biases significantly determine the homeowners' behaviours towards energy retrofits?

This dissertation investigated whether accounting for cognitive biases significantly improves the prediction of actual energy retrofit decisions (Chapter 4). The results show that when cognitive biases are taken into account, the prediction of homeowners' energy retrofit decisions is more accurate than when cognitive biases are not taken into account, which has also been confirmed in previous studies [94, 183, 371]. Namely, the model without cognitive biases calculated positive decisions for the individual homeowners regardless of their negative decisions. In contrast, the model considering the cognitive biases correctly estimated the decisions of 86% of homeowners. This dissertation was the first to investigate the cognitive biases for different target groups of households in the field of energy efficiency. The results of Chapter 4 show that the group of households that normally avoid losses invest more to prevent the further impact of losses on their lives. They also overestimate the probability of rare events, such as an explosion in the building, and therefore invest more to prevent the expected loss due to the rare events.

7.2.4 What are the main transaction cost barriers during the renovation process for the homeowners in the Netherlands?

TCs consist of information acquisition, negotiation, and monitoring costs [313, 316, 345]. Neglecting TCs in the assessment and preparation of energy efficiency policies leads to sub-optimal decisions and resource allocations [453]. This study was the first to develop a conceptual framework of TCs at different stages of the renovation decision-making process. The statistical and regression analyses revealed that TC barriers significantly hinder the process of renovation and energy retrofitting. TC factors are related to the type of renovation. The complexity of exterior renovation of buildings and access to reliable contractors to carry out exterior renovations, estimating the cost of interior renovations, and finding the most appropriate type of energy retrofit to improve energy efficiency are the main TC barriers to various renovations. Obtaining information on the appropriate type of energy retrofit is cited as the most important TC barrier. The most important sources of information for energy retrofits were also examined using regression analysis. The most important sources of information for homeowners are maintenance or installation companies.

7.2.5 How can the results of this dissertation be used to evaluate the potential misalignment of current policy in promoting energy efficiency retrofits in the owner-occupied housing sector in the Netherlands?

First, the core chapters of this dissertation investigated the main behavioural influencing factors for the decision-making process, second, examined the main transaction cost barriers for the energy efficiency retrofit process. Finally, the main identified influencing factors were used to explore the potential misalignment of current policy and provide recommendations for future policy instruments. Chapter 6 focused specifically on validating the findings of the key influencing factors through semi-structured interviews and focus group sessions with municipal project managers and practitioners working in the context of energy transition in the Netherlands. Based on the results of the core chapters, the potential misalignment in current policy is identified: (1) the lack of energy retrofits tailored to the needs of particular group of buildings and households, (2) the needs to use the right message and the right messenger of particular household group to promote energy retrofits, (3) the inadequate implementation of behavioural interventions and nudges to promote energy retrofit, and (4) the lack of integrated financial, informational and technical support especially for homeowners interested in energy retrofits. The identified discrepancies between key influencing factors and current policy are illustrated in the next section.

7.3 Policy recommendations

7.3.1 The lack of energy retrofit solutions tailored to the needs of particular types of buildings and households

The main factors influencing behaviour and the magnitude of impact differed considerably between different groups of households and buildings. However, the ranking of these factors did not change for the different types of energy retrofit measures. Building and household characteristics ranked first and second, respectively. Public and private companies need to provide tailored solutions for different groups of buildings and households as also supported by Broers et al. [60]; Vega, et al. [461]; A. Steenbekkers et al. [418]. As mentioned earlier, the data have also shown the importance of personal factors in the decision-making process. Therefore, the personal factors of different groups of people need to be taken into account when grouping households. Grouping people based on personal factors can be a very complex task. However, it can ultimately lead to more harmonious groups than categorising groups of households based on building and household characteristics.

The Netherlands and other European countries recognised the importance of tailor-made solutions. A more detailed harmonisation of household groups is critical, as the initial financial barrier still hinders the process of energy retrofits, especially for low and low to middle-income households. This group has difficulties financing the most common investments for a natural gas-free house, such as insulation and heat pump. The current subsidies are still too low for these groups to cover the costs. Moreover, one of the conditions for receiving subsidies is to pre-finance the initial costs of an energy renovation measure, and low-income groups often do not have such a reserve [393, 396]. Accurate categorisations of households using machine learning algorithm can reduce specific barriers for different groups. The public authorities should provide higher percentage of subsidies and lease energy retrofits of PV panels with lower payments to the low- and low-to-moderate-income household groups compared to high-income households as also mentioned by O'Shaughnessy et al. [341]. The local authorities must first identify household groups using key factors of households and building characteristics to accelerate the energy retrofit process. Second, the local authorities need to modify the original categories by considering cultural and social factors. Thirdly, the local authorities need to identify the best ways to reach, target and support specific household groups. Finally, the reliable providers of energy-efficient technologies in the market need to provide the most appropriate package of energy retrofit measures for homeowners.

7.3.2 The needs to use the right message and the right messenger for particular household group to promote energy retrofits

After classifying the different groups of households and buildings, policy makers need to promote energy retrofitting. Local authorities in the Netherlands are uncertain about the right message and ambassador to promote energy retrofits. This dissertation proposes the following approach to achieve more effective communication with households. First, the energy retrofit ambassador must use the key motivational factors of improving comfort, keeping the home in good condition, and saving on energy bills. Second, the identified main motivating factors differ depending on the type of energy retrofit that need to be considered by policy makers. Improving comfort is high on the list of motivating factors for double glazing and insulation. Maintenance is also high on the list for installing a sustainable heating system. People install PV panels to save energy costs (1st rank) and for the environment (2nd rank). Third, people are strongly influenced by the ambassador's perceived authority, commonality or shared identity, knowledge and trustworthiness, as explained by Dolan et al. [97]; Hornsey [201]; Tajfel et al. [430]. In the Netherlands, local authorities have to use a trusted person by the households to convince them to invest in energy retrofits. Households in the Netherlands perceive the local authority or housing association programme managers as third parties and resist their proposed measures to improve the sustainability of buildings. The importance of the right messages and different communication channels was also supported by Broers et al. [60]; Brander, et al., [54]; Steenbekkers and Scholte [419].

7.3.3 The inadequate applications of behavioural interventions and nudges to promote energy retrofits

The consideration of psychological factors is usually neglected in the promotion of energy retrofits. However, decision making in energy retrofits also strongly depends on psychological factors, including personal factors and cognitive biases. The aim of this dissertation was to provide some suggestions for increasing the use of behavioural measures in combination with traditional energy policies in the form of subsidies, loans, and tax cuts. First, the dissertation found that among personal factors, households that consciously reduced their energy consumption invested more in installing solar panels than households that did not consciously change their behaviour. This group needs to be identified and take the lead in adopting energy efficient technologies. Second, the current dissertation also shows the significant influence of cognitive biases on energy retrofit decisions.

Policy makers should use behavioural interventions to encourage energy retrofits. Potential behavioural interventions are suggested based on the results of chapter 4: (a) Illustrate the impact of installing energy retrofits in terms of reducing losses/costs for risk- and loss-averse individuals. Depending on the target group, the costs and losses can be financial, physical (safety/health), social (opinion of others), environmental (green or not), time and effort, functional (fitting into routine), and even psychological (how one feels about the investment) [147, 229, 405]. The message "The current technology in the house is 3 times less efficient than the new energy technology" is more effective than "The new energy efficient technology is twice as efficient as the current technology in the house." In addition, "You are currently losing 40 euros on your current heating system" is more effective than the message "You could save 40 euros by installing new energy efficient technology" [147, 378]. (b) Promote low-risk and safe energy-saving measures, such as money-back guarantees for new energy-efficient technologies and for risk-averse people.

7.3.4 The lack of an integrated financial, informational, and technical support to facilitate the energy retrofits for homeowners

Homeowners face difficulties in addressing financial, informational and technical requirements to conduct the energy retrofits. According to the results of this dissertation, financial barriers was one of the main categories of barriers to energy retrofits. This barrier occurred despite the extensive grants, loans and subsidies offered at both local and national levels. Consequently, this specific barrier may be related to transaction costs, such as the complexity of applying for loans and subsidies, household unawareness on availability of loans and grants, and the uneven distribution of loans and grants among households (as also emphasised in Elshof et al. [116]). In addition, TC barriers prolong the process of energy efficiency retrofit. Obtaining information on the right type of energy retrofits, lack of reliable information and lack of professionals are the main identified TC barriers in this dissertation. This dissertation proposes two suggestions to reduce the financial, informational, and technical barriers for homeowners.

First, the intervention of a third party or a new agency is needed to connect the different actors in the market. In this way, a lot of time, effort and costs can be saved, as the necessary services for the implementation of energy retrofits are provided by this agency. In the Netherlands, this type of agency has recently entered the market through public or private partnerships. Reimarkt and Regional Energy Desk are public and private companies that offer tailor-made solutions on an individual and neighbourhood level. These companies currently cannot provide services to all areas in the Netherlands. Therefore, the government or municipalities should encourage and facilitate the entry of these new intermediaries. In addition to this type of company, the concept of one-stop shops can help households to ask for help with all steps of energy retrofitting. The one-stop shop is currently in operation in few cities in the Netherlands. To expand energy retrofitting of residential buildings, support from other municipalities is needed. Recently, a very comprehensive guide on the role of energy desks in removing transaction cost barriers for homeowners has been published in the Netherlands. This guide highlights that energy desks should help homeowners find reliable contractors, provide information on no-regret measures, and that energy desks should even be made visible to homeowners [116, 456, 461]. Monitoring the accurate implementation of the guideline facilitate the process of energy retrofits for homeowners.[16]

Second, the new agency/broker can be a digital platform that matches homeowners with providers. TCs can be significantly reduced by providing the necessary information, reliable experts, and the essential knowledge and skills to carry out the energy retrofits. This approach is on the government's agenda. In Integrated Approaches for the Energy Transition in Existing Buildings (IEBB) project, a design of a digital platform is started. The *"www.verbeterjehuis.nl"* launched by Milieu Centraal is a very basic development of this kind of digital platform. The decision aid provides information about the orientation phase and for assessing which energy retrofits are suitable for the buildings, and the costs and benefits of the energy retrofits. In addition, a complementary decision support tool16 was developed to help homeowners determine if they are eligible for grants to make their buildings more energy efficient. The biggest pitfall of such a tool is the reliability and not considering the holistic and long-term impacts of multiple energy retrofits.

16 The Ministry of the Interior and Kingdom Relations and the Association of Dutch Municipalities (VNG), in collaboration with municipalities and energy desks, worked on this guide. https://www.verbeterjehuis.nl/energiesubsidiewijzer/

Third, the most desirable digital platform should address aspects related to homeowners. Key performance indicators should show the impact of energy retrofits on comfort, home maintenance status, and quality of life. TC barriers to implementation also need to be highlighted in terms of the complexity of processing information and finding information about energy retrofits. See also [402] for the characteristics of existing support tools in ten countries. Finally, it should also be noted that for the digital platform to be scaled up, certain initial conditions need to be met. Specifically, a sufficient number of providers and households must join the platform to achieve cost efficiency. When individual homeowners join the platform, it becomes more attractive for providers to join. This in turn increases competition and people can get higher quality energy retrofits at lower prices.

7.4 Added value of the research

7.4.1 Contributions to the scholarly knowledge

This dissertation contributed to the improvement of the home energy retrofit process by examining the key influencing factors and helping to facilitate and promote energy efficient home retrofits. The scholarly gap addressed in this dissertation was that much attention has been paid to the financial and technical barriers to accelerating energy retrofits, but little attention has been paid to behavioural factors and transaction costs in the literature. The innovative aspects of this dissertation arise from the integration of academic disciplines (research approach) and the empirical study of biases (research method): (a) the innovative approach has been the development of an integrated framework that provides a holistic view of the decision-making and renovation process. This framework encompassed the factors that influence behaviour and TC barriers at different stages of the energy retrofit process. In addition, this work combined insights from several academic disciplines, including behavioural science, new institutional economics, and housing quality and process innovation. These disciplines provided complementary knowledge to understand and analyse the behaviour of individuals in relation to energy retrofits in the housing sector. (b) the innovative method was to empirically investigate the cognitive biases of reference dependence, loss aversion, diminishing sensitivity, and probability weighting in energy retrofit.

7.4.2 Contributions to practice

This dissertation aimed to promote and to facilitate energy retrofit of owner-occupied homes in the Netherlands. The findings can help policy makers, homeowners and the suppliers of energy efficient technologies and services.

First, policymakers can use the main findings of this dissertation in designing or modifying future policies. Based on the main findings, this dissertation recommended a few policy implications. By applying these recommendations, policymakers can promote energy retrofits and reduce transaction cost barriers during the energy retrofit process for homeowners.

Second, homeowners can understand their benefits and limitations in implementing energy efficient retrofits. Based on the findings of this dissertation: (a) Homeowners can understand the benefits, available subsidies and loans of different types of energy efficient retrofits in the Netherlands. (b) Homeowners can understand the psychological barriers during their decision-making process. This awareness can help reduce the impact of cognitive biases. (c) Homeowners can also join sustainable living initiatives in their neighbourhood to collaborate with other neighbours and live more environmentally friendly. (d) Homeowners become aware of existing public and private entities that facilitate the implementation of energy retrofits by providing information and access to reliable contractors and professionals.

Third, service suppliers and energy-efficient technology providers can explore new business models to meet homeowners' energy retrofit needs. This dissertation recommended setting up a new agency and developing a digital platform to reduce the transaction cost barriers for homeowners. The supply and demand sides of the market and policymakers need to collaborate to enable setting up the new agency or the digital platform for the implementation of energy retrofits.

7.5 Limitations of the study and recommendations for future research

This dissertation aimed to provide a holistic overview of the factors influencing behaviour and the transaction cost barriers in homeowners' decision-making and renovation processes. Nevertheless, future research may consider the limitations of this dissertation in terms of scope, data collection, and methodology.

First, this dissertation addressed the factors influencing behaviour and the transaction cost barriers during the decision-making and renovation process of homeowners. The interaction of homeowners with other stakeholders has been neglected in this dissertation, and only the impacts of behaviour influencing factors and transaction cost barriers were investigated on the decision making and renovation process. However, homeowners interact with other stakeholders, such as businesses, institutions, and maybe neighbours to be able to perform energy retrofits. The involvements and interactions of many parties/entities make the renovation a complex system [1]. An agent-based model or system dynamics can be particularly used to model complex systems. An agent-based model can simulate the interaction between different agents (in this case, households, suppliers, and policy makers) when the population is heterogeneous and the individual is potentially different, the interaction is heterogeneous and complex, and the agents show complex behaviour, including learning and adaptation [28, 51]. In addition, policy impacts were not directly examined in this dissertation. Modelling system dynamic allows us to test policy instruments, learn dynamic complexity, understand the sources of policy resistance, and develop more effective policies [421].

Second, this dissertation investigated four cognitive biases of reference dependence, diminishing sensitivity, probability weighting, and loss aversion. The method for hypothesis testing was mathematical modelling. This type of study is less time consuming and inexpensive compared to experimental methods for hypothesis testing (e.g. lab or field experiments). Experimental studies manipulate the subjects' environment and measure their response to change. They provide convincing evidence by testing the subjects' actual behaviour compared to the information provided by household about their actual behaviour. The method of analyses can be the same statistical or regression analyses for experimental methods. For future research, the effects of cognitive biases, such as normative social influence, on energy retrofits can be investigated using experimental methods. An experiment could be designed to create five household groups. Then, different interventions are tested for each group, including the descriptive norm, self-interest (e.g., saving money), protecting the environment, social responsibility (e.g., for the future generation), and providing information (control group). Then the behaviour of these different groups must be observed over a period of time (at least one year). The results can show which group invests more in energy retrofits and consumes less energy compared to the others. Due to limited time and resources during the PhD, the experimental methods for hypothesis testing are planned for future studies.

Third, few assumptions are defined in the development and estimation of the parameters of the cumulative prospect theory (CPT). This dissertation considers the monetary benefits and costs of energy efficiency investments. Considering the transaction costs and non-monetary benefits of energy efficiency retrofits, such as comfort improvements, will increase the accuracy of predicting actual behaviour.

Finally, this dissertation falls into the category of cross-sectional data analysis, which refers to the analysis of data collected at a single point in time rather than over a period of time. Furthermore, based on the theoretical framework, five phases for renovation and energy retrofit are identified: consideration, planning, decision, implementation and experience. Due to the limited amount of data, only two phases of renovation were studied: planning and implementation. A more detailed analysis can be conducted if the behavioural factors and transaction cost barriers for each phase of the renovation are directly addressed by collecting data from different target groups. This can be done by collecting data in a time series. In this approach, individual behaviour can be monitored over a period of time.

Appendices

APPENDIX A

Research data

Qualitative and quantitative data are used in this thesis. The datasets provided by the Dutch national organisations are the most important ones. In the following subsections these datasets are described. Besides these datasets, data is collected through interviews and focus groups with experts in the field of energy and buildings. These data are mainly collected to validate the results of the quantitative studies.

The Netherlands housing survey 2018

The Netherlands housing survey includes the statistical information about the housing situation of the Dutch population and their housing needs and preferences. Examples of these statistical information are the composition of households, the home and living environment, housing costs, housing preferences and relocation. The target group is peo- ple older than 18 years old in the residential sectors in the Netherlands. This dataset is collected every three years and containing the information of almost 60 thousand respon- dents. The data collection methods are personal interviews, telephone interviews and, since 2009, also via the internet. Since 2009, the surveys are conducted by the Statistics Netherlands (CBS), in collaboration with the ministry of the interior and kingdom relations [311].

The Netherlands housing survey energy modules 2012 and 2018

The Dutch ministry of the interior and kingdom relations conducts a survey every 5 to 6 years on the energy consumption, energy behaviour of households, as well as the in- vestment behaviour of households with regard to energy-saving measures in the rental and private building stocks. This survey is carried out as a part of a larger survey of the Dutch dwellings (WoON – Woon Onderzoek Nederland, which translates as the Nether- lands Housing Survey). The target groups are the households in the owner-occupied, so- cial housing, and private rental sectors. The energy module also contains other variables that are collected through the dwelling inspections, reports on energy consumption, other datasets, such as the Netherlands Enterprise Agency (in Dutch: Rijksdienst Voor Onderne- mend Nederland (RVO)) dataset, including building characteristics, such as energy labels [416].

Data about the personal and motivational factors are mainly from the survey. The hous- ing and building characteristics are collected from sources other than the survey. In this study, the energy module 2018, the most recent one, is used. This database comprises 4506 dwellings in which 63% (2878) belong to the owner-occupied sector [278, 372].

From the energy module 2018, the following data are used: (1) renovators and poten- tial renovators; (2) different types of energy efficiency renovations, for example, double- glazing, insulation of the wall, roof, floor, solar PV-panel, and, sustainable heating; (3) contextual factors- household and building characteristics (part of the extracted data and not survey); (4) personal factors- the household perceptions on their behaviours are ques- tioned in different ways, for instance, whether they deliberately change their behaviour or how do they perceive themselves compared to other households in energy consumption; and (5) motivational factors to adopt the energy efficiency renovations.

The housing survey of the research institute for the built environment (OTB – Onderzoek voor de gebouwde omgeving).

A questionnaire survey was conducted among 3,776 homeowners in the Netherlands in 2012. The questionnaire comprised three sections: household and building characteris- tics, renovation (two categories: exterior and interior), and energy efficiency renovation. Homeowners were asked whether or not they had implemented a renovation in the last two years, and whether or not they planned a renovation in the next two years. The distinctive feature of this dataset is to categorise different types of renovations, and cover- ing more hindrances in conducting renovation and energy efficiency renovation, as well as, including higher number of individual owners in the dataset compared to the energy modules 2012 and 2018. The representativeness of this dataset was tested by comparing the descriptive main factors of household and building characteristics with the dataset provided by the Dutch government.

RVO dataset

The energy label database of RVO are used to calculate the renovation rates in the owner- occupied sector. This database includes every registered energy label for the years 2003- 2017 of different types of buildings in the Netherlands. In this thesis, only the owner- occupied residential sector are considered. According to the European Commission (EC) regulation, it is obligatory to determine the energy label of the dwellings that will be rented out or will be sold since January 2008. If the dwelling is renovated the owner has an incentive to update the energy label because a “better” energy label can increase the rental price and has a positive influence on the selling price. Consequently, some buildings have more than one registered energy label. This makes it possible for us to track the renovation rate of the housing stock. However, one should realise that many buildings, and therefore also renovations, are not registered because dwellings that are not sold or rented out are not obliged to register their energy label. In 2017, this dataset contains the information of 284 thousand homeowners in the Netherlands.

CBS open data STAT-line and microdata

CBS opendata Stat-Line is an open access data that provides information for different sectors including the buildings and constructions. The data includes the share of different sectors of the total residential sector, energy consumption for different sectors, and etc. CBS opendata Stat-Line contains information on the housing stocks such as the share of different sub-sectors of private, rental, and social housing, energy consumption per sector, etc. The CBS microdata database is not open access. The organisations, such as universities can make a subscription to use the specific data for research purposes. For instance, the actual energy consumption per individual dwelling with encrypted address is included in the database. The original Energy label database of RVO doesn’t contain information about which sector the dwellings belong to. Therefore, the database is linked to a database from Statistics Netherlands. The CBS microdata database distinguishes three different sectors: owner-occupied, subsidised rental, and unsubsidised rental sector.

APPENDIX B

Woon energy module 2012

Description

WOON energy module database enables answering questions about energy labels, energy savings in the dwelling stock, the influence of the behaviour of residents and investments in energy-saving measures. A survey is conducted including 87 questions and focuses on the energy efficiency of the dwelling sector. It consists of the following parts:

Part 1: Dwellings and households' characteristics (10 questions)
The questions are about the household composition, age, tenure status, living period, number of occupant, hours at the house during the day, and how often households are at home.

Part 2: Heating and ventilation (10 questions)
The questions are about temperatures in the living room in the presence and absent of occupants, average temperature during the heat season, setting of the temperature on the thermostat for a weekday during the heat season, ventilation of living rooms/other rooms during the heat season.

Part 3: Energy and water (7 questions)
The questions are about energy source for cooking, number of cooking hot meals, shower time and number per week, water saving shower.

Part 4: Energy saving (10 questions)
The questions are about energy saving activities, gas and electricity consumption, comparison of energy consumption with others, perception of energy efficiency by the households, the importance of energy efficiency behaviour, barriers to energy efficiency renovations, reliability of sources of information, pleasant of the house.

Part 5: Investments in the house (29 questions)
This section contains questions about investments that have been made in the house in the past five years. Then questions are asked about the possible investment plans for the next two years. Two types of investments are distinguished:

A Housing maintenance - improvement and / or expansion such as exterior paint- ing, facade repairs, installation of an extension, conservatory or dormer.
B Energy efficiency renovations such as insulation, double glazing, replacement heating boiler or installing solar panels.

The householders replied to the questions, such as if they have done/ will do a ren- ovation, the type of investment, their motivations (maximum three reasons), who paid and did the work, the amount of subsidies, the role of subsidies in their decision, the actual cost, are For each type of investment

Part 6: Leaking roofs and wood consumption (19 questions) A number of questions are asked about the roof of the house or storage space.
The WOON energy module consists of 1112 variables.

APPENDIX C

Energy efficiency technologies

This section describes the importance and advantages of using four types of EERs of double glazing, insulation, PV panels, and sustainable heating. These advantages are explained in terms of energy-saving, thermal and acoustic comfort, and environmental benefits. Based on the survey of 2018, the majority of homeowners has invested, or has planned to invest, in these four types of EERs compared to the others in the Netherlands.

Double glazing. Double glazing was originally introduced in the United Kingdom to keep the building warm during the winter and it has been used extensively since the 1980s [161]. In recent years, double glazing is now used as the standard type of glaz- ing for new buildings [157]. The heat loss from the windows has the greatest share in the total heat loss of a building. As the thermal transmittance values for double glazing is almost half of that for single glazing, the installation of double glazing can improve the energy- efficiency for heating and cooling of a building, substantially. Double glazing also enhances the thermal and acoustic comfort levels in the indoor environment [158, 164, 412, 429, 449]. According to a study in the the United Kingdom, replacing single glazing with double glazing can potentially result in 39-53% of energy-saving in the commercial build- ing sector [311]. Application of double glazing in hot climate is crucial for improving the comfort of building occupants, as well as increasing safety in case of fire. Reducing sound transmission and infiltration, around windows are mentioned as other advantages of dou- ble glazing in comparison with single glazing, according to a study in the United States [303].

Insulation of wall, roof, And floors. Practitioners perceive thermal insulation as the best way to diminish the energy consumption for HVAC systems, and to reduce the heating and cooling losses [120, 198]. Buildings with a well-insulated envelope and ad- vanced double glazing windows consume much less energy, due to lower losses [20, 449]. Ardente et al. [20] conducted energy and environmental assessments of various EERs for public buildings within European countries. The most beneficial EERs are mainly associ- ated with high-efficient windows and thermal insulation of walls.

Thermal insulation results in less reliance on the mechanical/electrical systems for keeping the internal temperature comfortable in the buildings. Lower usage of mechan- ical/electrical systems provides environmental benefits by reducing the GHG emission produced, and also consuming less energy by these systems. As the investment cost for installation of thermal insulation is relatively low compared to the total construction costs (5% of total construction costs), it could result in lower total energy costs by reducing the size of the required HVAC equipment.

Insulation can also decrease the noise disturbance from the neighbourhoods/ outdoor environment. Therefore, as with double glazing the acoustical comfort of well-insulated dwellings would be higher. Suitable design and installation of thermal insulation can pro- hibit vapour condensation on the building exterior. Vapour barriers are usually applied to hinder moisture penetration into low-temperature insulation. The energy-saved due to thermal insulation also brings in other benefits, such as saving resources for future generations, and making energy available to the other consumers [198].

Solar photovoltaics (PV) panel. A photovoltaics panel refers to a module that absorbs sunlight and produces electricity, and these were invented in 1992 [470]. PV panels are the most applicable renewable energy technologies for the buildings in the urban en- vironment. The main advantages of PV panels include their mild environmental impact, and that, in use, they produce no noise or chemical pollution during usage [450]. Nev- ertheless, their wider scale use might result in negative environmental impacts, such as excessive water usage, or chemical pollution due to the usage of hazardous materials in manufacturing processes [450].

Modern PV systems can provide a direct supply of clean electricity supporting the de- mand of a dwelling, and can be connected to private consumption infrastructure. This would diminish the GHG emission produced from the consumption of fossil fuel. The easy integration of PV panels into buildings has resulted in the rapid uptake of this prod- uct in several countries across the world [463]. PV panels can also solve the problems of electricity shortage in rural areas. In this case, a PV generator is generally cheaper than connecting to the long-distance main grids [450]. In recent years, the costs of PV power for both residential and non-residential sectors has noticeably decreased, on av- erage, 13%–18% per year between 2009 and 2014 (based on a study in Portugal). In the Netherlands, Dutch parties are aming to decrease the cost of solar PV panels further by reducing the price by 30% by 2025 compared to 2020 [306].

Sustainable heating. According to a study in the United Kingdom, on average 55% of the energy bills are accounted for by the efficiency of the boiler. New boilers recover more heat because of having a larger surface area of heat exchangers. Also, this study shows that, for an average dwelling, replacing a “G”-rated boiler with an “A”-rated one leads to approximately €375 saving per annum [50, 118]. In the Netherlands, almost 50% of the energy bills is associated with the heating, and a further 13% with hot water. In the Netherlands, the plan is to gradually replace gas boilers by electric heat pumps and district heating [302].

There are multiple sources for sustainable heating: from sustainable electricity/biogas, solar boilers, restored summer heat in soil, deeper layers of the earth, and air. Zago et al. [488] analysed the differences in primary energy consumption and efficiency among sev- eral independent and centralised heating systems installed in Northern Italy. The authors concluded that the installation of centralised heating systems reduce the energy consump- tion by 6.1-11%. In addition, solar-heated domestic hot water saves approximately 27-29% of primary energy consumption. The usage of this technology is highly recommended together with the centralised heating systems. Kelly and Cockroft [235] used monitored data and simulations to investigate the performance of air source heat pumps (ASHP) after renovations in the United Kingdom. The results indicate that use of heat pump can result in 12% reduction in carbon emission compared to the use of an equivalent condensing gas boiler, at 10% higher cost for ASHP. However, since the United Kingdom government supports the usage of re- newable heat sources and the net costs of using ASHP would be lower. Salata et al., [386] examined the benefits of replacing conventional boilers with an integrated system of a co-generator (CHP) and a heat pump (HP). By improving the energy label, annual energy cost saving as well as lower gas emission and negative environmental impacts are the main reported advantages. Ala, Orioli, and Di Gangi [14] evaluated the energy-economic analysis of the use of air-to-air heat pumps compared to using gas boilers. The heat pump profitability increases with higher thermal energy consumption.

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Biographical Note

Shima Ebrahimigharehbaghi was born in Tehran, Iran. She graduated from Tehran University with a Bachelor of Science degree in Agricultural Engineering and specialisation in Economics. Seeking higher education, she earned a Master of Science in Economic System Programming from the National University of Iran in Tehran. She graduated with honours with the first top rank among other graduated master students. She was then immediately offered to work as an economic researcher at Arya Sahm Economic Research Co. In 2012, she decided to continue her education and gain experience abroad. She got a scholarship from Technology, Policy, and Management Faculty of TU Delft to continue her education. She moved to the Netherlands, where she completed a Master of Science in Engineering and Policy Analysis at Delft University of Technology which is a highly multidisiplinary master track covering economics, management, and policy analysis. After completing her master's degree, she was eager to continue her research, and to apply her educational background, especially in the field of sustainability. In 2017, she wrote a proposal and met with Prof. Dr. ir. H.J. Visscher and Dr. Queena K. Qian, who agreed to supervise her as a potential PhD student. In parallel with her PhD, she worked on other projects related to energy efficiency in the building sector at OTB, a research institute for the built environment. For these projects, she had the previlege to work under the supervision of Prof. L. Itard, Prof. Marja Elsinga, and Dr. Harry van der Heijden. These projects later led to publications in various journals.

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22#06

Understanding the decision-making process in homeowner energy retrofits

From behavioral and transaction cost perspectives

Shima Ebrahimigharehbaghi

In 2020, owner-occupied housing accounted for 57% of the housing stock in the Netherlands. Homeowners are fully responsible for the implementation of energy retrofits. Moreover, the processes of energy retrofitting are complex and homeowners face problems such as finding financial support, reliable information and contractors. The complexity of implementing energy retrofits may discourage homeowners from continuing the process and achieving the expected benefits. Behavioural aspects and transaction costs (TC) are among the most important factors influencing consumer decision-making processes. Behavioural factors primarily illustrate a range of personal, contextual, and external factors that influence the decision-making process of homeowners. These include cognitive awareness and biases, attitudes and beliefs, experience and skills, homeowner characteristics, sociodemographic characteristics, property characteristics, and the behaviour of others. TC are any hidden costs that influence decision making but are not included in the direct physical costs of renovation services and products. This dissertation developed an integrated framework of behavioural factors and TC that impede the decision-making process for energy retrofits. Key findings include (1) the significant importance of behavioural factors and TC barriers. (2) the behavioural factors are particularly important in the early stages of energy retrofits and the TC barriers after the final decision. (3) the importance of behavioural factors and TC barriers differs according to the type of energy retrofit and non-energy retrofit. (4) Accounting for cognitive biases significantly improves the prediction of households' actual decisions about energy retrofits. This modelling is more accurate than the model that assumes households make rational decisions.

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