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The willingness of social housing tenants to participate in natural gas-free heating systems project: Insights from a stated choice experiment in the Netherlands

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HIGHLIGHTS

- Increasing social housing retrofit contributes to the energy transition.
- Determine attributes in promoting tenants' interest in energy-efficiency renovations.
- Captured the preference heterogeneity by a mixed logit model.
- Observe heterogeneous preferences among latent class membership respondents.
- Gain and hedonic motives exert key roles in attracting tenants' willingness to participate.

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ABSTRACT

One of the main tools to achieve the promise of carbon neutrality is the energy transition. Reducing dependence on traditional energy and promoting the use of renewable energy drives changes in the energy sector and contributes to the energy transition. The building sector is strongly linked to energy consumption and retrofitting the building sector with natural gas energy is a positive energy efficiency strategy. This research aimed to determine the factors influencing social housing tenants in the Netherlands to participate in retrofits and to identify the differences among participants in their preferences. Using a stated choice experiment and discrete choice model, 380 effective social housing tenants in the Netherlands participated. The estimated Mixed Logit Model (MLM) reveals the preferences of social housing residents, and the Latent Class Model (LCM) indicates differences between latent groups. The results show that social housing residents are attracted by saving total housing costs, enhancing living comfort, providing a new bathroom, kitchen and toilet of individual houses and improving the neighbourhood environment. Meanwhile, they are resistant to the interference generated during the renovation process. These findings can be used to guide government and housing organisations in developing retrofit programs that align with the needs and preferences of social housing tenants.

1. Introduction

Rapid urbanisation is accompanied by many environmental problems. The increase in energy consumption has contributed to an increase in greenhouse gas emissions, thereby putting pressure on the sustainable development of the environment [23,66]. The emergence and increase in the frequency of extreme weather are symptomatic of this problem. The slow transition towards renewable energy structure and excessive energy usage result in elevated carbon emissions, which are important reasons for these problems. Therefore, attention to the optimisation of energy systems can help alleviate problems and provide opportunities for sustainable energy development.

Like most countries, the building sector in the Netherlands, especially the residential sector, accounts for a significant share of energy consumption [10,52,68]. The energy efficiency of buildings depends heavily on the heating system [38,48,63]. The energy consumption of the Dutch residential sector is mainly due to space heating, and the objective is to reduce this demand by two-thirds by the year 2050 [68]. Adopting environmentally friendly heating systems in residential buildings can reduce energy consumption, lower energy production

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costs, and decrease greenhouse gas emissions, positively impacting the environment. In addition, residential space heating is closely related to issues such as energy supply security and rising energy prices. It is crucial to prioritise stable energy efficiency, supply, and cost-saving measures in residential buildings from both a technical and economic standpoint [40,41]. Therefore, improving energy efficiency in the building sector has an important impact on total energy consumption and can make an important contribution to achieving Sustainable Development Goals (SDGs) in affordable and clean energy as well as sustainable cities and communities.

The energy transition is a potential solution and future orientation for urban energy conservation and emission reduction. It is the transition from a traditional fossil-based energy system to new environment-friendly energy to achieve sustainable energy strategies and zero carbon emissions [12,54]. Following the European climate goals, the Dutch government has proposed an energy and climate transition initiative (National Climate [44]). The construction sector in the Netherlands aims to replace traditional gas heating systems with alternative options for approximately 7 million houses. Besides, there is a specific target to renovate 1.5 million houses to enable their potential utilisation of electricity from renewable sources (National Climate [31,44]). Many countries and governments highly recommend natural gas-free strategies as classic energy transition solutions. A few studies were concerned with researching social housing tenants' evaluation of the household heating system to support energy conservation. For example, Huebner et al. [24] have shown that tenants are concerned with heating, and cost savings is the main factor affecting their willingness to conserve energy. Dell'Isola et al. [15] researched apportionment methods for heating cost allocation and proposed that charging all tenants for additional consumption could encourage energy-efficient retrofit interventions. Factors such as heating costs, electricity generation costs, carbon emissions, and electricity prices have a major impact on domestic households [49]. These studies illustrate that people are directly connected to the heating system and are likely to be attracted to energy transition approaches. However, the adoption decisions of social housing tenants were influenced by incomplete information and inattention and the type of information offered [46]. In addition, due to legal restrictions, natural gas-free renovation projects can only be promoted with more than 70% tenant support in the Netherlands [7,46]. In order to develop effective policy measures and enhance the outcomes of building energy efficiency investments, it is crucial to comprehend the determinants that impact tenants' decision-making and willingness to participate in natural gas-free renovation projects. By addressing this gap, valuable insights can be gained to inform policy development and promote greater energy renovation in sustainable energy initiatives.

To better understand the willingness and preferences of social housing tenants to participate in energy conservation and transformation initiatives, and to promote energy transformation according to their needs, the aim of this study, therefore, is to explore social housing tenants' willingness to participate in a natural gas-free renovation project, with specific emphasis on their expectations and involvement in the participation process by using a stated choice experiment. The research study provides theoretical support and contributes to the practical implementation of energy transition strategies for natural gas-free renovation in the building sector, with a specific focus on social housing. The findings of the study will offer valuable recommendations for policymakers, housing authorities, and stakeholders involved in the development of sustainable and affordable housing solutions. Besides, this research contributes to advancing energy transition efforts in social housing and provides support for communities to achieve Sustainable Development Goals (SDGs).

The rest of the paper is structured as follows. Section two presents a comprehensive literature review, examining prior research and scholarly contributions relevant to the topic. The intricate methodology employed are outlined in section three. Section four explains the data collection and demographic information of respondents, and section five provides the empirical result. Section six offers a discussion. The conclusion, implementation, limitation and recommendation are presented in the final section.

2. Literature review

The willingness to participate in natural gas-free renovation projects is influenced by three goals that influence pro-environmental behaviour, specifically, the gain, hedonic and normative goals [4,58].

2.1. Pro-environmental behaviour

Pro-environmental behaviour (PEB) is behaviour that positively alters the structure and dynamics of an ecosystem or biosphere, reflecting an individual's active interest in environmental issues and the resulting positive attitudes and behavioural tendencies [35,37,60]. Steg et al. [56] proposed that exploring people's sustainable energy behaviour plays a key role in facilitating energy transition as people's engagement is encouraged by features of environmental traits, which are associated with their preference for PEB. Besides, motivation acts as an important factor to determine people's enthusiasm and participation in sustainable energy behaviour [56].

2.2. Motives

The gain motive aims to preserve or improve a person's resources [34]. A Dutch study of the influence of values on people's perception and adoption of energy alternatives found that people are sensitive to incentives information, especially changes in personal resources [34]. Gain is often used as the main motivation of the goal frame, which is reflected in the fact that when the benefits obtained exceed the costs associated with the behaviour, people are more possible to participate in environmentally friendly behaviours [34]. The desire to obtain benefits, which is related to altruistic and egoistic motives often motivates people's energy-sufficient behaviour [33].

The hedonic frame leads people to focus on the things that affect their pleasures, mood, and energy level [34,61]. It is described as people refusing negative effects and tending to feel excitement and pleasure as it focuses on their feelings and mood [34]. People usually choose to do a task that easily offers them positive emotion rather than a challenging one. Such research in consumer behaviour revealed that if people gain values and satisfaction easily, they intend to join in pro-environmental behaviour [18,56].

Normative concern, introduced by de Groot & Steg [13], refers to people's behaviour that is motivated by a sense of responsibility towards the environment. Norms are associated with self-expectations and external expectations. Some studies have confirmed that the Normative goal promotes people to be concerned on provide benefits to the external environment or people. [56,61,62]. The characteristics of Norm make Even when people have different goals, they rarely act completely egotistically.

2.3. Demographic factors

In addition, demography is an essential factor impacting people's perception of the energy transition. For instance, a positive correlation has been observed between the acceptance of energy transformation measures and education level [8,17,25] where highly education level people are more open to energy renovation measures. As energy investment has the characteristics of high investment with low operational comfort, a relationship between the energy investment behaviour in households and age-related variables emerged, which could be either positive or negative. For instance, elderly uncertainty about whether the investment will pay off during the remaining time they live in their homes could lead to a negative effect [25,28,43]. Household composition, especially those with young children, are more likely to be interested in energy retrofit projects [43]. Also, other socio-demographic indicators such as income, occupation, and time of ownership may have a relationship with people's willingness to join energy renovation [17,43].

However, while some research has focused on the motives that influence an individual's pro-environmental behaviour, there is a lack of understanding regarding the influence of different motives on individuals' willingness to participate in natural gas-free renovation projects, as well as the mechanisms underlying their decision-making processes. Furthermore, the interaction between these motives and demographic factors also warrants further investigation. In summary, the research is innovative in exploring the role of motives in promoting individuals' participation in natural gas-free renovation projects. By understanding the impact of motives on people's willingness to participate and their decision-making processes, as well as considering demographic factors, the research can pave the way for innovative solutions to promote natural gas-free renovation.

3. Methodology

3.1. Stated choice experiment

In order to assess the residents' preference for participating in off-gas renovation projects, the study employed a stated choice experiment (SCE) to explore the influence of different attributes on residents' preference for energy transformation alternatives. The stated choice experiment is commonly used to capture the participants' preferences and trade-offs between various attributes. Many researchers have proven that it can predict and explain future market behaviour when respondents face new choices or hypothetical alternatives [36,65]. Therefore, it is a relevant approach to quantify the willingness of social tenants to participate in natural gas-free renovation projects [46,58]. The development of a design of an SCE consists of two stages: (1) selection of relevant attributes and definition of levels, (2) design of choice alternatives' attribute profiles. The researchers conducted a literature review on the topic of natural gas-free transition to determine the relevant attributes to support the design of the SCE.

3.2. Attributes selection

Based on a literature review, the study selected six attributes, including new heating system technology, total housing cost, living comfort, nuisance, house improvement, and neighbourhood improvement. Table 1 shows the attributes and levels with explanation details.

The new natural gas-free heating system is good for the environment,

Table 1
Attributes and level description.

Attributes	Level
New Natural Gas-Free Heating	1. Heat Network with New Radiator 2. Heat Network without New Radiator 3. Heat Pump on Electricity 4. Heat Pump on Electricity and Green Gas
Total Housing Cost (Rent and energy costs)	1. Pay €10/month less than the current cost 2. Pay €5/month less than the current cost 3. Pay the same as the current cost 4. Pay €10/month more than the current cost
Living Comfort	1. Better 2. A Little Better 3. Remains the Same 4. A Little Worse
Nuisance	2. Little Nuisance 1. Lots of Nuisance
House Improvement	2. None 1. New Bathroom, Kitchen, Toilet
Neighbourhood Improvement	2. None 1. Neighbourhood Get Better and Problems have Been Fixed.

as it replaces a gas-fired heating system [21]. The provision of knowledge of pro-environmental behaviour helps to deepen people's understanding of norms [61,62]. In the context of pro-environmental behaviour, normative information could drive respondents to choose an alternative environmentally friendly heating system [21]. The new heating system consists of four levels, in specific, heat network with new radiators, heat network without new radiators, heat pump on electricity and heat pump on electricity and green gas. The heat network is split into with and without new radiators, as heat networks have different operating temperatures based on the type of heat source. A low-temperature heat network and an old radiator limit the supply of heating, which means that in this circumstance, it is suggested to replace radiators in order to match the heat supply. However, it is not necessary to replace the radiators if higher-temperature heat sources are in use in the heat network. The heat pump is also split into heat pump on electricity and heat pumps on electricity and green gas. The electric heat pump is limited to apply only in combination with good insulation since an uninsulated dwelling in winter challenges an effective electric heat pump. Combined with green gas, an electric heat pump can apply also in an uninsulated dwelling in winter. It means electric heat pumps support the heating in dwellings most of the months in a year. The green gas adds to cover the heat demand when the electric heat pump cannot fully support heat demand in the winter.

Referring to the literature, Abreu et al. [1] described that homeowners consider housing adjustments based on many variables, such as time and money. Their results showed that residents were willing to make a considerable investment in energy retrofitting and expect a return on their investment that exceeds the initial cost, primarily through savings on their energy bills [43]. Wilson et al. [64] studied the parameters of homeowners' willingness to participate in energy-efficiency renovations and found that the financial and economic benefits, as well as the size of the investment, were the main drivers in the decision-making process. Hauge et al. [22] explored the factors that influence the likelihood of residents or homeowners of housing cooperatives agreeing to sustainable retrofitting and concluded that economic factors are the main influence in the decision-making process. Research in motivations for investment in renewable energy in the community found that the gain motive is often the focal goal in the decision-making process, while the lack of financial resources was the main barrier to participation [16,30,53]. Considering that the renovation projects are invested in and funded by the housing association, the tenants should primarily take into account the change in the rental cost and energy cost rather than investment. Social housing rental costs are mainly determined by factors such as the size of the room, the functional amenities such as kitchens and toilets, and the value of the property [57]. This suggests that implementing energy efficiency measures is unlikely to significantly reduce or increase the overall expenses of tenants renting a house. Therefore, the research stated that the levels of total housing cost per month (including rent and energy costs) decrease by 10 euros, and 5 euros, remain the same and increase by 5 euros, respectively, on the basis of the current level.

The living comfort is described as draft and temperature change in the dwelling in relation to the current situation of the tenant. The different function of the heating system affects the heating in the dwelling and result in a change in airflow and ventilation, which relates to living comfort. The change in the living environment can be referred to as hedonic motives, as increasing comfort is enjoyable and makes people feel pleasant while decreasing comfort can result in negative feelings [47,55]. People paid attention to house changes since it relates to the enjoyability of the current state of their house [39,47]. However, living comfort will not change dramatically with the transition from gas to non-gas heating systems. Therefore, the levels of living comfort attributes are set as better, a little better, remains the same, and a little worse.

Another concern of tenants is the nuisance caused by the renovation. Nuisance is considered as the disruption of daily living. It acts as a (negative) hedonic motive for pro-environmental behaviour because it describes the tenant's resistance to the extra effort to achieve comfort and benefit [14,26]. A negative relationship between nuisance caused by renovation projects and participation has been found in several studies [9,59]. Nuisance is caused by various reasons such as preparatory construction measures or work, which will temporarily decrease the tenant's living comfort. It is important to take into account that this experience of discomfort is highly influenced by the duration of the renovation project. Since it is challenging for respondents to discriminate different levels of nuisance, the research offers this attribute with two levels including a little nuisance and lots of nuisance for clear clarify convenience.

The attribute of relevant house improvements can be defined as the renovation of the bathroom, kitchen, and toilet (BKT) in a house [2,67]. Kovacic et al. [32] indicated that BKT renovation is one of the most important reasons for sustainable renovation. People enjoy their improved houses because the renovation provides them with feelings of pleasure related to gain and hedonic value [6,45]. However, tenants often pay an extra charge for rent for a renovated house which influences their gain value. Therefore, it is possible to combine renovating for a natural gas-free design with BKT so that the renovation will provide the tenant with clear benefits. The levels endowed to this attribute are whether the tenant receives a new BKT, or not.

Neighbourhood improvement often consists of the quality of the neighbourhood enhanced by improving the aesthetics of environments through developments such as green space, landscaping, and water drainage [42]. Also, the renovation that encourages social cohesion, such as reducing elderly isolation, could be attributed to the improvement of the community [50,71]. At the same time, some measures, such as reduction of nuisance and litter and solving parking space problems, will contribute to the physical environment in a neighbourhood [69]. Therefore, neighbourhood improvement is driven by three behavioural motives including hedonic, gain, and normative motives [19,27,29]. The improvement of the neighbourhood environment not only satisfies tenants' gain and hedonic motives in improving the surrounding environment but also contributes to the creation of a sustainable neighbourhood environment, which aligns with normative values. The levels for neighbourhood improvement were the neighbourhood will be improved, or no improvement.

3.3. Experiment design

The stated choice experiment application involves creating designs that combine levels of attributes in a specific way. In this study, the experiment has three four-level attributes and three two-level attributes, which results in $4^3 \times 2^3$ possible profiles in a full factorial design. Due to the fact that the resulting number of 512 profiles is challenging in management, the study reduced the number of profiles by creating an orthogonal fractional factorial design. The orthogonal fraction selected includes 32 profiles of this total. These 32 profiles were randomly combined to form 16 choice sets, each containing three options. To alleviate respondent burden, only 8 out of the 16 choice sets were presented to each participant. This resulted in the creation of two versions of choice sets, with each version containing eight choices. The version of choice sets presented to each respondent was determined randomly. Each choice set comprised two choices with five alternatives and one choice to retain the current heating system. Throughout the experiment, participants were asked to indicate their preferred option from the presented choices, allowing them to trade-off between attributes such as heating types, housing cost, living comfort, nuisance, house improvement, and neighbourhood improvement based on their individual preferences. In order to accurately identify the target sample, the participants were also asked to indicate whether they were a tenant of a housing association at the outset. An example of a stated choice set presented to the respondents is shown in Table 2.

3.4. Mixed logit model

Discrete choice modelling is an established method widely used in describing, explaining, and predicting choices between discrete alternatives [35–37,65]. It is a utility-based decision model which aims to understand the underlying factors that drive an individual's decision-making process. The elements of a choice typically include the decision maker, the alternatives available, the attributes of each alternative, and the decision rule used. Discrete choice modelling can be used to understand preferences for activities, services, and facilities, which is applied in various research topics, including energy, transport, and social science research. For instance, Azarova et al. (2019) used the method to assess the social acceptance of comprehensive energy transition and provided suggestions for building renewable and sustainable energy systems [5]. Also, it is found that the majority of participants have a high likelihood of participating in a web-based household energy conservation program in their neighbourhood [11]. Employing discrete choice experiments contribute to energy research in exploring customers' willingness to join energy conservation and other non-marketed energy products [51]. The utility equation can be defined as:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

$$V_{ij} = \sum_n \beta_n \times X_{ijn} \tag{2}$$

where,

U_{ij} is the utility individual i assigns to alternative j.

V_{ij}: is the structural component of individual i's utility for alternative j.

ε_{ij}: is the random component of individual i's utility for alternative j.

β_{jn}: weight of attribute n in the utility of the alternative j.

X_{ijn}: The value of alternative j on attribute n faced by individual i.

In the study, the variables considered include a new heating network, rental cost, living comfort, house improvement and neighbourhood improvement. The random effects of the attributes were considered. Therefore, the weight of the utility of each attribute (β) was assumed to follow a specific distribution in order to account for heterogeneity. All random parameters were assumed to follow a normal distribution with β and density f. The probability of an individual n choosing an alternative is given by:

$$P_{nit} = \int L_{nit}(\beta) f(\beta|\theta) d\beta \tag{3}$$

3.5. Latent class model

The Latent Class Model (LCM) is a statistical method used to identify

Table 2
An example of a choice set.

Features	Choice A	Choice B	Choice C (Current Heating)
New Heating Network	With New Radiator	Without New Radiator	/
Total Housing Cost	€10 less/Month	€10 more/ Month	/
Living Comfort	Remain the Same	Better	/
Nuisance	A Lot of Nuisance	Little Nuisance	/
Dwelling Improvement	New Bathroom, Kitchen and Toilet	None	/
Neighbourhood Improvement	Better	None	/
Choice One Option			

and analyse patterns. The model estimates parameters based on individual response patterns on explicit indicators [20]. The method aims to identify underlying patterns or categories within a group of individuals, based on observable variables, which can be used to group individuals into distinct classes in terms of their preferences that exist within an unobserved group. In a latent class model, each individual is assigned to a class based on their probability of membership in that class. The model is estimated by maximising the likelihood of the observed data given the underlying latent structure.

The LCM has often been used in transportation, energy, and environmental research. In this study, the tenant's preferences regarding attributes of a natural gas-free renovation project are assigned to a group based on the similarity of preferences of participants. The parameters are estimated for each class. In addition, a group of observable characteristics such as socio-demographic variables and willingness to participate factors entered the model for the prediction of class membership.

Therefore, the central behavioural model of LCM is a logit model for discrete choice. The probability of an individual i who belongs to class q choosing alternative j from a particular set t can be calculated with the following formula.

$$P_{i,t,j|q} = \frac{exp\left(V_{itj|q}\right)}{\sum_{1}^{J} exp\left(V_{it,j|q}\right)} \tag{4}$$

where,

$V_{itj|c}$ is the utility of alternative j for individual i in a choice set t given class q.

In an LCM, each class q has a set of parameters and it is possible to assign class membership probabilities of individuals based on the choice pattern they display and predict class membership based on given person variables included in the model. In this study, individual characteristics (including socio-demographic variables, satisfaction with housing association, environmental attitude and willingness to pay) are used to explain class membership. Each individual i will be assigned to the class with the highest probability based on the choices made. Using a logit model, the probability is determined using the following equation [72].

$$H_{iq} = \frac{exp\left(Z_i^{'}\theta_q\right)}{\sum_{q=1}^{Q} exp\left(Z\theta_q\right)} \tag{5}$$

H_{iq}: The prior probability for individual i for class q.

Z_i: The set of observable characteristics of individual i.

θ_q: A latent class parameter vector to be estimated.

4. Data collection and socio-demographic profile

4.1. Questionnaire design

The questionnaire contains three sections: (1) the stated choice experiment, (2) statements regarding living comfort, willingness to pay (WTP), knowledge, satisfaction with the housing association, trust in the housing association, and environmental attitude; (3) questions about socio-demographic characteristics. As for the statements, the respondents were invited to give a score based on a 5-point Likert scale, which ranged from 1 (strongly disagree) to 5 (strongly agree), The questionnaire was implemented in LimeSurvey, a convenient tool for an online survey to conduct data collection. At the beginning of the questionnaire, a privacy statement was presented that corresponds with the term and conditions of the Ethics Committee of the university. Also, a video with the introduction of natural gas-free heating systems, the SCE, and the different attributes and levels of the experiment was presented to participants. In addition, the questionnaire was available in Dutch and English versions for selection in case of literacy problems.

The study included two rounds of pilot testing of the questionnaire. The first-round pilot was used to test the comprehensibility of the questionnaire. With feedback, some presentation issues were improved in the introduction video and the choice experiment. In the second stage, 15 social housing tenants were invited to fill out the questionnaire. Multiple housing associations were requested to review the invitation and questionnaire to improve the efficiency and attractiveness of the invitation.

The actual data collection process continued from January 2021 to March 2021 in the Netherlands. Considering the lockdown policy for COVID-19 during the experiment period, the survey was conducted online and completed by respondents electronically. This survey has received support from several housing associations that manage social housing in neighbourhoods across various provinces in the Netherlands, including Limburg, Overijssel, Gelderland, North Brabant, Groningen, and Zuid-Holland. These housing associations are usually important housing associations in their respective municipalities, and each manages a substantial number of housing units, ranging from 2700 units to over 27,000 homes. Based on the household address and contact information provided by several housing associations in the Netherlands, we sent an invitation letter containing a hyperlink and QR code. The letter was sent via email, post mail, Facebook, and LinkedIn, in order to make it easier for social housing tenants to access the survey website.

We sent approximately 5590 invitation letters to invite tenants to participate in the survey. With 1067 completed questionnaires returned the response rate was 19%. The initial round of checks involved eliminating incomplete questionnaires and samples from non-social housing tenants, ultimately resulting in the retention of 481 samples. In the second round of data review some invalid responses, such as consecutive same answers in the choice experiment and unreasonable completion time, were identified and removed. At last, the sample of 380 responses was used for further estimation. The valid response rate was around 7%.

4.2. Socio-demographic characteristics of participants

Table 3 indicates the detailed descriptive statistics of the sample. As shown, 24% of respondents born between 1952 and 1961, followed by those born between 1962 and 1971 (20%). The proportion of survey respondents born between 1952 and 1961 is larger than the actual

Table 3
Descriptive statistics of the sample.

Items		Frequency	Percentage	Netherlands percentage
Year of Birth	1941 and older	25	7%	6%
	1942 to 1951	66	17%	11%
	1952 to 1961	93	24%	14%
	1962 to 1971	76	20%	19%
	1972 to 1981	53	14%	18%
	1982 to 1991	48	13%	16%
	1991 to 2001	19	5%	17%
Gender	Male	168	44%	50%
	Female	212	56%	50%
Education	Elementary School	20	5%	9%
	Secondary Education	277	73%	58%
	Higher Education (HBO, WO)	83	22%	33%
Work Status	Work	196	52%	71%
	Not work	55	14%	17%
	Retired	129	34%	12%
Number of Children	0	282	74%	67%
	1	49	13%	14%
	2	34	9%	14%
	3 or More	15	4%	5%
Monthly Household Income	Less than €1791	133	35%	33%
	€1791 to €2212	86	23%	6%
	€2213 and above	95	25%	43%
	No answer	66	17%	17%

population of the same age group in the Netherlands, whereas the proportion of respondents born between 1990 and 2001 is only 5%, which is significantly lower than the national average of 17%. This phenomenon can be attributed to the likelihood of some respondents in these age groups residing with their family members. The proportion of female respondents (56%) respondent sample is higher than that of male respondents (44%). The distribution of education status reveals that most of the respondents are trained in secondary education (73%), which is higher than the national level. This is consistent with the observation that social housing tenants typically have education levels that are lower than the average education levels in society [3]. About half of the tenants have paid work (52%), while 34% of residents are retired. The percentage of individuals aged 65 years or older is higher than the percentage at the national level. This is likely due to a higher proportion of older individuals residing in the social rental sector on average [3]. As for household composition, a relatively high percentage of tenants reported having no children (74%), while only 15 respondents (4%) have 3 or more children. Moreover, 35% of the respondents earn less than €1791, and 23% of them earn between €1791 and €2212 in a month. The household income of the social housing sample is significantly lower on average than that of the Dutch population. In general, these samples partially represent the Dutch socio-demographic landscape and mirror the circumstances of social housing tenants.

5. Results

5.1. Descriptive and statement analysis

The research conducted a factor analysis to extract tenants' considerations and perceptions on participating in natural gas-free renovation projects. Exploratory factor analysis (EFA) was used in the analysis and the analysis extracted 3 factors out of 16 variables, which can be labelled s satisfaction with the housing association, willingness to pay and environmental attitude. Table 4 shows the result of EFA.

5.2. Model estimation result

The study employed a mixed logit model and a latent class model to estimate tenants' preferences for participating in natural gas-free renovation projects. The variables of willingness to pay, rental allowance, household composition, having children, and year of living were used as independent variables in the class membership function estimated.

The study has tested several values for *K,* which is the number of classes in the latent-class model. It was found that increasing the class quantity did not increase the model performance. Two classes of participants were found sufficient to explain the data properly. Therefore, the study selected the latent class model with two classes. The estimation results for the two classes are shown in Table 5. Class membership was determined based on several variables, including willingness to pay, lack of rental allowance, household composition (specifically, single-family homes), and having children. Table 5 shows the estimated parameters of MLM and LCM.

The study compared the MLM and LCM results. The Halton method was used to perform 1000 random draws for MLM estimation. The value of the Log-Likelihood for the MLM model and LCM model is −3208.0, and − 2453.4, respectively. The Mc Fadden's Rho^2 value for MLM is 0.200. Also, the result reveals that the LCM has a satisfactory model fit as the adjusted Rho-square values are 0.231, which is higher than the cutoff of 0.200. The result implies that both the MLM and LCM models have enough explanatory ability while the LCM performs better than MLM.

Compared to the base level of that attribute, a positive coefficient in the above Table 5 shows that the level of the attribute increases the utility, and a negative value decreases the utility. The result of MLM informs that paying 10 euros less (0.399) and 5 euros less (0.134) per month makes tenants more likely to consider participating in an energy

Table 4
EFA result.

Variables	Composition		
	Satisfaction with HA	Willingness to Pay	Environmental Attitude
Trust my housing association.	0.839		
Satisfied with the way my HA sends messages.	0.804		
Would recommend my HA to family and friends.	0.803		
Satisfied with the amount of letters/emails my HA sends.	0.803		
My HA adheres to agreements.	0.782		
Satisfied with the level of involvement in my HA decision-making.	0.714		
Satisfied with my HA communication on energy transition.	0.670		
Would pay more if the dwelling is more comfortable.		0.768	
Would pay more if dwelling is better for the environment.		0.755	
Would pay more if energy bill decreases.		0.685	
Would pay more if could get a new BKT		0.659	
If we continue like this, a major natural disaster will soon come.			0.719
Nature and the environment are strong enough to survive.			0.666
Human is in charge of the rest of nature.			0.518
Something clever will be invented so that the world will not become uninhabitable.			0.380
Few places and resources that we have to share on Earth.			0.379

Note: HA refers to housing association; BKT refers to bathroom, kitchen, and toilet.

transition renovation project. As the monthly total housing cost rises by 10 euros more (−0.585), tenants' willingness for taking part in the energy transition renovation project declines. With the decreasing level of living comfort, tenants pay less interest in joining a renovation project. As shown, the better (0.371) and a little better (0.168) living comfort positively influences participants' preference for accepting natural gas-free renovation significantly. On the contrary, a worse living comfort (−0.736) diminishes people's preferences. Also, a lot of nuisances (−0.444) act as a negative factor for tenants' natural gas-free renovation preference. A new BKT (0.241) raise residents' preference for renovation. Similarly, if the neighbourhood is improved (0.216), residents are more likely to prefer to join in the natural gas-free renovation.

Table 5 presents the standard deviations of the random parameters in the mixed logit model, indicating the degree of preference heterogeneity among individuals. The results show that the standard deviation for the option of heating without a radiator and a heat pump powered by electricity is significant, suggesting that there is significant variation in preferences for this level. The standard deviation of paying less than 5 euros per month for renting is also significant, indicating that not all respondents may have the same preference for off-gas renovation despite paying less. While the standard deviation of paying 10 euros more per month is significant, it suggests that not all tenants would be

Table 5
Result of MLM and LCM.

Attributes	Level	Mixed Logit Model		Latent Class Logit	
				Class 1	Class 2
		Coefficient	St. dev.	Coefficient	Coefficient
Constant		0.848***		2.189***	−0.789**
New Natural Gas-Free Heating	1. With New Radiator	−0.013	0.003	0.010	−0.085
	2. Without New Radiator	0.009	0.480***	0.002	−0.065
	3. Heat Pump on Electricity	−0.015	0.369***	−0.036	0.167
	4. Heat Pump on Electricity and Green Gas	–	–	–	–
Total Housing Cost	1. Pay €10/month less	0.399***	0.025	0.279***	0.389***
	2. Pay €5/month less	0.134**	0.371***	0.145***	0.146
	3. Pay as same as the current cost	–	–	–	–
	4. Pay €10/month more	−0.585***	0.431***	−0.413***	−0.667***
Living Comfort	1. Better	0.371***	0.315***	0.385***	0.027
	2. A Little Better	0.168***	0.022	0.179***	−0.155
	3. Remains the Same	–	–	–	–
	4. A Little Worse	−0.736***	0.086	−0.625***	−0.322***
Nuisance	1. Little Nuisance	–	–	–	–
	2. Lots of Nuisance	−0.444***	0.335***	−0.314***	−0.395***
House Improvement	1. None	–	–	–	–
	2. New Bathroom, Kitchen, Toilet	0.241***	0.563***	0.205***	0.048
Neighbourhood Improvement	1. None	–	–	–	–
	2. Neighbourhood Get Better	0.216***	0.094	0.168***	0.110
Theta 01	Constant (ONE)			1.845*	
	Willingness to Pay			0.620***	
	Rental Allowance: No			0.296*	
	Household composition: Single Family			−0.131	
	Have Children			−0.084	
	Year of Living: 0 to 1			−0.705***	
Log-Likelihood		−3208.0		−2453.4	
Mc Fadden's Rho^2		0.200		0.235	
Adjusted Rho-squared		0.200		0.231	

Notes: *** significant at 1% level, ** significant at 5% level and * significant at 10% level.

willing to pay the same amount for the energy transition renovation project. Some tenants may be willing to pay more than 10 euros per month, while others may not be willing to pay that much. The result also implies that tenants have diverse levels of enthusiasm towards better living comfort. The significant standard deviation of nuisance suggests that not all tenants are equally affected by the presence of nuisance. Some tenants may be more sensitive to nuisance, while others may be less so. A similar interpretation could be drawn for the house improvement, i.e., that not all tenants place the same value on it. The significant standard deviations of these factors highlight the importance of considering individual preferences and need when making decisions about renovation projects. No one-size-fits-all solution exists for increasing tenants' participation in the energy transition renovation project.

The MLM model accounts for individual heterogeneity in preferences, while the LCM model identifies the presence of different classes of individuals with different preferences. The variable estimation coefficient in the class model describes the participants' characteristics. It appears that socio-demographic and statement variables, including willingness to pay, rental allowance, household composition, and year of living, impact membership probabilities significantly. A positive coefficient implies a high probability of belonging to class 1, as class 2 is set as a reference. For instance, tenants with high willingness to pay characteristics are likely to be of class 1. Similarly, people who do not receive a rental allowance are more likely to belong to class 1 rather than class 2. Also, living in the house for less than one year is negative, meaning that those people are more likely to be part of class 2.

In the LCM, the constant in class 1 is 2.189, which is higher than the negative value for the constant (−0.789) in class 2. A high constant reflects that, as a base preference, individuals in class 1 have a high probability of accepting the two alternatives of new natural gas-free renovation options. In contrast, individuals in class 2 are less likely to participate in a natural gas-free renovation project.

The results of the latent class model (LCM) suggest that total housing cost, living comfort, and nuisance are important factors in determining the likelihood of tenants participating in a natural gas-free renovation project. The results show that paying less than 10 euros per month is an attractive factor for both class 1 and class 2 tenants, with class 2 tenants showing a slightly higher interest than class 1 tenants. Additionally, paying less than 5 euros per month has a positive impact on class 1 tenants, but it does not play a significant role in class 2 tenants' decision-making. On the other hand, the results indicate that an increase in total housing cost by 10 euros per month has a negative impact on both class 1 and class 2 tenants' willingness to participate in the renovation project. However, class 2 tenants appear to be more sensitive to housing expenditure than class 1 tenants, with a greater negative impact (−0.667) on their decision-making compared to class 1 tenants (−0.413).

Living comfort is another factor that influences tenant preference for acceptance of the renovation. The results show that a decrease in living comfort negatively affects both classes. For example, Class 1 (−0.625) shows a stronger negative feeling than Class 2 (−0.322) for a little worse living comfort. On the other hand, better living comfort plays an important role in promoting individuals in class 1 to attend natural gas-free renovation projects.

Nuisance is also a significant factor that influences tenants' decision to participate in an off-gas renovation project. The presence of a lot of nuisance has a negative impact on the willingness of both class 1 and class 2 tenants to join the project. The results also indicate that house and neighbourhood improvement are important factors that play a role in class 1 tenants' preferences. A renovation project that includes the addition of a new BKT can attract the interest of class 1 tenants, with a positive effect of 0.205 on their willingness to participate. Similarly, a better neighbourhood can also increase class 1 tenants' willingness to join the renovation project, with a positive effect of 0.168.

The results of both models generally align with each other. Specifically, the attribute of paying €10/month less demonstrates significance, with values of 0.399 in the MLM model, 0.279 in class 1, and 0.389 in class 2, respectively. Besides, a little worse living comfort has a significantly negative effect on tenant participation preference in both the MLM model (−0.736) and the LCM model (class 1: −0.625, class 2: −0.322). Similarly, the presence of numerous nuisances negatively impacts tenants' preferences in both the MLM model (−0.444) and the LCM model (class 1: −0.314, class 2: −0.395). There is a slight difference observed in better living comfort, with a significant positive value of 0.371 in the MLM model and 0.385 in class 1 of the LCM model. However, this attribute shows a non-significant result for class 2 individuals. As for the attribute of new BKT, it has a significant positive effect in the MLM model (0.241) and class 1 of the LCM model (0.205). However, this attribute is non-significant for class 2 individuals.

6. Discussion

The study compared the performance of two different models, the mixed logit model (MLM) and latent class model (LCM), in explaining the likelihood of tenants participating in natural gas-free renovation projects. The results indicated that the LCM outperforms the MLM in explaining tenant participation. The findings highlight the significance of considerations in tenants' decision-making.

The results show that a reduction of 10 euros per month in rent and a reduction of 5 euros per month make tenants more likely to consider participating in the energy transition renovation. On the other hand, an increase of 10 euros in total housing costs negatively impacts tenants' willingness to participate. These findings emphasise the importance of affordability in encouraging tenant engagement. Living comfort emerges as a crucial factor influencing tenants' preferences. Improved living comfort, both significantly better and slightly better, positively affects tenants' preference for accepting a natural gas-free renovation. Conversely, a decrease in living comfort diminishes tenants' interest in participating in the renovation project. The presence of nuisance negatively impacts tenants' preferences for a natural gas-free renovation. The study finds that a lot of nuisances act as a deterrent for tenants, reducing their inclination to join the renovation project. Furthermore, the inclusion of new facilities, such as a new BKT, enhances tenants' preference for renovation. Similarly, improvements in the neighbourhood positively influence tenants' willingness to participate in a natural gas-free renovation.

The LCM analysis identifies distinct classes of individuals with different preferences. Socio-demographic and statement variables, including willingness to pay, rental allowance, household composition, and length of residency, significantly impact the likelihood of belonging to specific classes. The LCM results indicate that individuals in class 1 exhibit a higher probability of accepting natural gas-free renovation options, while individuals in class 2 are less likely to participate in such projects.

The findings of the study indicate that tenant participation in housing initiatives is primarily influenced by three key factors: total housing cost, living comfort, and nuisance. The study found that paying 10 euros less per month was attractive to both class 1 and class 2 tenants. An increase in total housing cost by 10 euros per month negatively impacted both classes. Similarly, nuisance plays a negative role in attracting tenants' preferences. Living comfort was also found to have a significant impact on tenant preference for the renovation, with a decrease in living comfort negatively affecting both classes.

In summary, the study reveals the influence of factors affecting tenants' preferences and willingness to participate in a natural gas-free renovation. Cost considerations, living comfort, nuisances, and improvements in facilities and the neighbourhood play significant roles in tenants' decision-making. The results highlight the importance of considering individual preferences and tailoring renovation projects to meet diverse tenant needs.

7. Conclusion and Implementation

Energy consumption and carbon emissions pose a significant threat to the environment and challenge sustainable development in urban areas. Therefore, promoting energy transition has become a crucial strategy for urban planning and public policy to achieve energy conservation and emission reduction goals. In Europe, reducing reliance on traditional fossil fuels such as natural gas has become a major concern for governments and cities [70]. This goal and trend have led to the development of natural gas-free renovation initiatives that prioritise environmental conservation and energy crisis reduction. The purpose of this study was to assess the factors that influence social housing tenants' acceptance of natural gas-free renovation projects. To achieve this, a stated choice experiment was designed to understand tenants' preferences for energy transformation projects and the attributes that impact their participation. 2500 social housing tenants in the Netherlands were invited to participate, and 380 valid responses were received. The study used the MLM and LCM methods to conduct analysis and compared the performance of the two models. In explaining tenant participation, the results revealed that the LCM outperforms the MLM. The result shows that New Natural Gas-Free Heating, total housing cost, living comfort, nuisance, and house improvement has a significant impact on tenants' participation. Besides, the LCM result reveals the difference in preference between the two class respondents. In short, the research offers valuable insights into the heterogeneity preferences of tenants and emphasises the significance of considering individual preferences and demands when making decisions regarding renovation projects. The study makes significant contributions to both theoretical understanding and practical applications.

7.1. Theoretical contribution

The study has a significant theoretical contribution as it enriches existing literature on the value of social housing tenants' preferences in energy transition and explains differences across tenants. The study investigated social housing tenants' priority in participating in natural gas-free renovation projects and adopted gain, hedonic, and normative motives as the main motivators and barriers to discovering tenants' perceptions. A potential theoretical contribution is the determination of the link between obtaining gain and hedonic value and social housing tenants' willingness to participate in an environmentally friendly renovation project. Furthermore, the study identifies the prevailing diversity within individual choice preferences. The results showed that there is significant variation in preferences among individuals, highlighting the importance of considering individual inclinations and demands when making decisions about renovation projects.

7.2. Practice contribution

The study elucidated the key drivers of social housing tenants' participation in natural gas-free retrofitting and identified preferences for different classes of tenants. The findings of this study have significant implications for the development of effective energy transition strategies in social housing.

To encourage tenant participation in the natural gas-free renovation project, several key factors should be considered. For example, since the reduction of total housing expenditure will attract tenants' willingness to participate, the housing association should consider alleviating the economic pressure on residents with regard to housing expenditures. Another crucial aspect is improving living comfort, which can significantly attract residents to participate in the project. By providing information and knowledge related to the renovated living environment about the positive impact and benefits of the energy system renovation on ventilation and temperature control, residents' interest in participating will likely increase. Both house and neighbourhood environment play a pivotal role in encouraging tenant participation. A wellmaintained and pleasant living environment is more likely to attract residents' willingness to be part of the renovation project. Therefore, the renovation plan should incorporate options that not only focus on energy facility renovation but also consider optimising housing conditions to make them more appealing to the residents. In addition, a repaired and enhanced neighbourhood environment is important. A clean and inviting neighbourhood will further motivate residents to participate in the project, as they will feel more connected and invested in their community [71]. On the contrary, nuisances have a negative impact on tenants' interests. Therefore, the renovation projects are suggested to enhance efficiency and minimise disruptions to the tenants' living.

Furthermore, in promoting the natural gas-free renovation initiative, special attention should be given to people who are willing to pay for the renovation and do not have housing allowances. These individuals are more likely to embrace the renovation plan and actively participate in it. Differently, individuals who have lived in their current residences for less than a year may be less willing to participate in the natural gas-free renovation project. As such, additional efforts may be required to engage this particular group and address any concerns they may have.

The research identifies crucial factors influencing tenant participation in energy-efficient retrofits and provides valuable insights for stakeholders in the building sector. By taking careful consideration of these factors and tailoring the renovation approach, the government and housing association can effectively attract tenants' willingness to participate and ensure the success of the natural gas-free renovation project. Besides, given that social housing in the Netherlands holds significant importance in the country's housing policy, garnering support from most tenants in a social housing building is essential for successful renovations. In this context, the study offers valuable suggestions for attracting more tenants and gaining their support for the natural gas-free retrofit in social housing. By incorporating these insights into the renovation strategy, the housing association can foster greater acceptance and cooperation from tenants, further advancing the adoption of energy-efficient practices in social housing. Moreover, the study's findings significantly contribute to the broader objective of achieving the Sustainable Development Goals (SDGs). By advocating for energy-efficient retrofits, these strategies actively contribute to the realisation of the SDGs, fostering sustainable and resilient communities.

7.3. Limitation

The research has some limitations. Firstly, due to the pandemic, the study relied on an internet-based approach for data collection. However, this method may inadvertently exclude individuals who do not have internet access. For future research, it would be beneficial to employ a combined method that includes both online and onsite data collection. Secondly, the version of the online investigation tool used in the experiment period had a limitation where the choice sets distributed to respondents could only be fixed. It is recommended to employ the random choice set method to avoid bias for further research.

7.4. Future research

The analysis conducted in this study has the potential for extension to other energy transition methods within the country. Also, exploring the preferences of other types of housing users or owners for alternative energy transition approaches presents another promising avenue for future research. Furthermore, this study can serve as a valuable reference for other countries aiming to promote their energy transition initiatives. By drawing insights and lessons from this research, these countries can enhance the effectiveness of their energy transition projects and contribute to sustainable future development.

CRediT authorship contribution statement

Xuan Liu: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Dujuan Yang:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Theo Arentze:** Writing – review & editing, Supervision, Conceptualization. **Tom Wielders:** Methodology, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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