Joint Discussion Paper Series in Economics

by the Universities of
Aachen • Gießen • Göttingen
Kassel • Marburg • Siegen

ISSN 1867-3678

No. 13-2026

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Preferences for energy retrofits: Empirical evidence from a stated choice experiment among homeowners and landlords in Germany

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Abstract

This study investigates the preferences of homeowners and landlords for energy retrofits in Germany using a large-scale stated choice experiment with 1,752 homeowners and 859 landlords. Using realistic, individualized choice scenarios and mixed logit models, we estimate preferences and willingness to pay for a broad set of technical, economic, and ecological energy retrofit attributes and examine how individual financial characteristics shape retrofit decisions and subsidy responsiveness. The results indicate that landlords are more likely than homeowners to opt for retrofits. Homeowners express a strong preference for heat pumps and high insulation, while both groups strongly reject fossil fuel heating and value CO_2 emission reductions. Notably, in both groups, debt aversion serves as a major barrier to energy retrofits, while limited access to capital and low income create additional constraints for homeowners. Furthermore, we find that subsidies have substantial non-monetary value, acting as risk-reducing tools that enhance decision-making confidence. This risk-reducing effect of subsidies is particularly pronounced among homeowners who perceive a high financial burden. Overall, our findings show that effective energy retrofit policy must be tailored to specific contexts. A one-size-fits-all approach is insufficient. To be successful, climate policy in the residential sector requires context-sensitive, tailored instruments that address the unique motivations and constraints of homeowners and landlords alike.

Keywords: Energy retrofits, Stated choice experiment, Mixed logit model, Willingness to pay, Subsidies, Residential climate policy

JEL classification: D12, D81, Q41, Q48

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1. Introduction

Combating climate change is one of the greatest challenges of our time. In the 2015 Paris Climate Agreement, 195 countries agreed to limit global warming to well below two degrees Celsius, ideally to below 1.5 degrees Celsius above pre-industrial levels (United Nations, 2015). The European Union aims to achieve climate neutrality by 2050, while Germany has pledged to reduce its greenhouse gas emissions by at least 65 % by 2030 and by at least 88 % by 2040, compared to 1990 levels. Germany aims to become climate neutral by 2045 (Umweltbundesamt, 2025).

However, in 2025, Germany's greenhouse gas emissions had only been reduced by around 48 % compared to 1990 levels (Umweltbundesamt, 2026). The building sector, particularly the residential building sector, has not yet contributed sufficiently to achieving Germany's targets. According to the Federal Environmental Agency (UBA), buildings accounted for around 15 % of total greenhouse gas emissions in Germany in 2025. This figure is only slightly lower than that of the transport and industrial sectors, which accounted for around 22 % and 21 %, respectively (Umweltbundesamt, 2026). Reducing greenhouse gas emissions in the building sector is therefore essential if Germany is to meet its national climate targets.

In 2024, Germany's residential building stock stood at around 19.7 million buildings. Around 24 % of residential buildings in Germany were constructed before 1950, and a further 36 % were built prior to 1980. Around 73 % of the heat generated in residential buildings comes from fossil fuel heat generators, i.e., oil and gas heating systems (Deutsche Energie-Agentur, 2026). These figures demonstrate the need for comprehensive measures to reduce greenhouse gas emissions in residential buildings, such as improving insulation and switching to renewable energy sources for heating.

A notable feature of the German housing market is that Germany has the highest proportion of tenants of any country in the European Union. More than 55 % of German households live in rented accommodations (Statistisches Bundesamt, 2020). This means that for a significant proportion of residential buildings, landlords, rather than homeowners living in the properties themselves, make decisions on energy retrofits.

Against this backdrop, we examine the preferences of homeowners and landlords for energy retrofits using data from a large-scale online survey in Germany. In the survey, we implemented a stated choice experiment in which participants could choose between different energy retrofit options and a no-retrofit option. The retrofit options differed in terms of a number of economic, technical, and ecological attributes, including, among others, investment costs, replacement of the heating system, the scope of insulation measures, and CO_2 emissions.

By doing so, we contribute to the existing literature in multiple ways. First, previous literature on energy retrofit choices has focused mainly on the replacement of heating systems, such as Lang et al. (2021) and Ruokamo (2016), or insulation measures (e.g., Banfi et al., 2008; Galassi and Madlener, 2017) alone. Notable exceptions are the studies by Achtnicht (2011), Phillips (2012), and Achtnicht and Madlener (2014), which incorporated a combination of heating system replacement and insulation measures into their choice experiments. However, the studies by Achtnicht (2011) and Achtnicht and Madlener (2014) only included homeowners who lived in their own properties. The study by Phillips (2012) included homeowners, tenants, and landlords but employed a relatively restrictive experimental design that offered only two levels (all or nothing) for the insulation and heating attributes. We address these issues by considering a range of levels for heating system replacements and insulation measures, and by including both homeowners and landlords in our survey and experiment.

Second, by incorporating financial factors such as subsidies, access to capital, and debt aversion into our experimental design, we expand the existing body of research on financial incentives and burdens for energy retrofits and energy efficiency policies (e.g., Olsthoorn et al., 2017; Fanghella et al., 2023). In particular, we build on the work of Schleich et al. (2021) and Schleich et al. (2022), who investigated the role of access to capital and debt aversion in retrofit decisions, as well as the monetary and non-monetary effects of subsidies on homeowners' decisions to replace heating systems in several EU countries.

Finally, the choice situations presented to participants are highly individualized, with the costs and CO_2 emission levels shown depending on the participants' previous answers in the survey. This makes the experiment and the choices that participants make more realistic than in previous studies without any individualization (e.g., Phillips, 2012; Ruokamo, 2016). Overall, our empirical approach, which involves a large sample of German homeowners and landlords, enables us to provide a comprehensive overview of the drivers and barriers of energy retrofits in the residential housing sector and to derive valuable policy recommendations to promote energy retrofit activities in this sector.

The remainder of the paper is organized as follows: Section 2 describes the data collection process, the experimental design, and the econometric approach. Section 3 presents the estimation results. Section 4 concludes and provides some policy implications.

2. Data and methodology

To answer the research question, we analyze data from a stated choice experiment implemented in a large online survey of private households in Germany. In this section, we first present the data collection and sample, then the design of the choice experiment, and finally the econometric approach.

2.1. Data collection and sample

Our empirical analysis is based on data from two surveys of household decision makers in Germany who live in their own house or apartment (homeowners) or rent out a house or apartment (landlords). The surveys were conducted between July and November 2022 in cooperation with the professional market research institute Psyma. Psyma was responsible for programming the questionnaire, hosting the surveys, and, in particular, managing the recruitment process.

To obtain a sample representative of homeowners who make decisions in Germany, Psyma first recruited participants according to the official quota for age, gender, place of residence (i.e., federal state), and high school graduation rate. In a second step, only participants who indicated that they live in their own house or apartment and that they are solely or jointly responsible for the purchase of major household items or services (e.g., vehicles, furniture, electricity contracts) were allowed to proceed with the questionnaire.

For the landlord sample, a quota sampling recruitment process was not possible because landlords represent a relatively small proportion of the total German population. Therefore, the recruitment process was based on a best-effort approach. The goal was to obtain a sample of approximately 1,000 participants who indicated that they rent out a house or apartment. Similar to the homeowner sample, only landlords who also indicated that they are solely or jointly responsible for the purchase of major household items or services were allowed to proceed with the questionnaire.

In addition, to ensure data quality, several quality control questions were included in both questionnaires, and participants who answered any of these questions incorrectly were excluded from further questioning. Also, based on Psyma's experience and guidelines, low-quality interviews with unreliable fast response behavior or unusual straight line ticking behavior were excluded. As a result of this procedure, we received a sample of 2,161 decision-making homeowners and a sample of 1,034 decision-making landlords from Psyma.

Based on these two samples, a final data quality check was performed, excluding participants who reported unrealistically low or high annual heating costs in the homeowner sample and unrealistically low or high monthly net rental payments in the landlord sample. For this purpose, we calculated the expected annual heating costs based on the reported living space, building type, construction period, and an assumed heating price of 6 cents per kilowatt hour. This price comes from the German Federal Statistical Office (Statistisches Bundesamt, 2023) and is the five-year average price, rounded to the nearest cent, that private households had to pay from 2017 to 2021 for natural gas, the most commonly used energy source for heating in Germany. We then compared these values with the reported annual heating costs in the homeowner sample and excluded homeowners who reported annual heating costs that were more than 50 percent above or below the expected annual heating costs. In this way, 409 participants were excluded, resulting in a final sample size of 1,752 homeowners for our analysis.

Similarly, we calculated the monthly net rental payments per square meter based on the reported monthly net rental payments and the size of the dwelling in the landlord sample. We then compared these values with the average net rent per square meter at the federal state level, obtained from the German Federal Statistical Office (Statistisches Bundesamt, 2020), and excluded landlords who reported net rental payments per square meter that were more than 50 percent above or below the average net rental payments per square meter at the federal state level. This resulted in the exclusion of 175 participants and a final sample of 859 landlords for our analysis.

The questionnaires consisted of several parts. First, some screening questions were asked for the sampling procedure. The second part included questions on economic preferences, personal values and attitudes, and political preferences. The third part contained questions on environmental and climate attitudes, as well as energy and environmental literacy. In the homeowner questionnaire, this was followed by questions on the housing situation, such as property ownership and finances, heating technology and heating costs, building condition, and energy retrofit considerations. The landlord questionnaire asked similar questions about the rented property and the current tenancy. The fifth part included a stated choice experiment on energy retrofits, followed by some questions on housing policies, the war in Ukraine, the coronavirus pandemic, and health status in the sixth part. The questionnaires ended with socioeconomic and sociodemographic characteristics, and in the case of homeowners, a short survey experiment on dynamic electricity tariffs.

Table 1 provides an overview of the sociodemographic characteristics of the sample of homeowners and landlords. The variable '*age in 10-year increments*' is the respondent's age divided by 10. The variable '*female*' takes the value one if the respondent identifies as female, and the variable '*high education degree*' takes the value one if the respondent has at least an advanced technical college degree or a university degree. Finally, the variable '*household size*' includes the number of persons who permanently live in the respondent's household. The figures in the table show that, on average, landlords are slightly younger and more educated than homeowners. The gender distribution and the average household size are almost identical in both groups.

Table 1: Sociodemographic characteristics of homeowners and landlords

Variables	Homeowners			Landlords		
	Mean	Std. dev.	Min-Max	Mean	Std. dev.	Min-Max
Age in 10-year increments	5.24	1.49	1.8-9.0	4.98	1.42	1.8-8.2
Female	0.48	0.50	0-1	0.47	0.50	0-1
High educational degree[a]	0.32	0.46	0-1	0.39	0.49	0-1
Household size	2.43	1.10	1-11	2.52	1.18	1-8
Number of respondents	1,752			859		

Table 2 presents summary statistics on the building characteristics of homeowners and landlords.[1] All variables are dummy-coded, meaning they take the value one if the respondent indicated the characteristic named by the variable and zero otherwise. The figures in the table show that homeowners mainly live in detached (57 %) and semi-detached (21 %) houses with 1-2 apartments. Landlords, on the other hand, are more likely to rent out apartments in multi-family houses with several apartments. Most frequently, the rental units are located in multi-family houses with 3-12 apartments (38 %).

In terms of construction year, the distribution in both groups is very similar. More than 60 % of both homeowners and landlords live in or rent out a house or apartment built between 1949 and 2001. In terms of the heating system, the distribution is again very similar. Fossil fuel heating systems are dominant in both groups. The most common are gas-fired heating systems, with more than 50 % in both groups, followed by oil-fired heating systems, with more than 20 %. The use of pellet heating systems and heat pumps is low, at about 3 to 6 %. District heating is used by 8 % of homeowners and 14 % of landlords.

We also asked about the general condition of the house or apartment using a five-point Likert scale. The variable '*good condition*' is equal to one if the respondents rated the

[1]Landlords who rent out several apartments or houses were asked about the characteristics of the apartment or house that has been rented out the longest. For homeowners who live in their own house or apartment, the questions are related to the main residence.

Table 2: Building characteristics of homeowners and landlords

Variables	Homeowners			Landlords		
	Mean	Std. dev.	Min-Max	Mean	Std. dev.	Min-Max
Detached house with 1-2 apartments	0.57	0.50	0-1	0.33	0.47	0-1
Semi-detached house with 1-2 apartments	0.21	0.41	0-1	0.19	0.39	0-1
Multi-family house with 3-12 apartments	0.17	0.37	0-1	0.38	0.49	0-1
Multi-family house with 13 or more apartments	0.06	0.23	0-1	0.10	0.30	0-1
Construction period: before 1949	0.17	0.38	0-1	0.16	0.37	0-1
Construction period: 1949-1978	0.31	0.46	0-1	0.30	0.46	0-1
Construction period: 1979-2001	0.34	0.47	0-1	0.36	0.48	0-1
Construction period: 2002-2015	0.13	0.33	0-1	0.15	0.36	0-1
Construction period: after 2015	0.05	0.21	0-1	0.03	0.17	0-1
Heating system: oil	0.24	0.43	0-1	0.22	0.41	0-1
Heating system: gas	0.52	0.50	0-1	0.51	0.50	0-1
Heating system: pellet	0.06	0.24	0-1	0.04	0.20	0-1
Heating system: heat pump	0.05	0.22	0-1	0.03	0.18	0-1
Heating system: district heating	0.08	0.27	0-1	0.14	0.34	0-1
Heating system: night storage and other	0.05	0.21	0-1	0.06	0.23	0-1
Good condition	0.73	0.44	0-1	0.77	0.42	0-1
Retrofit: Insulation	0.50	0.50	0-1	0.60	0.49	0-1
Retrofit: Heating or ventilation	0.51	0.50	0-1	0.57	0.50	0-1
Retrofit: Solar thermal or PV	0.19	0.40	0-1	0.24	0.43	0-1
Number of respondents		1,752			859	

general condition of their house or apartment as good or very good, and zero otherwise. In both groups, more than 70 % of respondents indicated that their house or apartment is in good or very good condition. Regarding retrofits made in the last 10 years, 50 % of homeowners stated that they had made improvements to the insulation in at least one of the following areas: roof or ceiling insulation, exterior wall insulation, basement floor insulation, or windows and doors. Similarly, 51 % reported making improvements to heating or ventilation. In contrast, only 19 % of homeowners reported installing a solar thermal or photovoltaic system. The percentages are higher for landlords for all three measures. 60 % of landlords reported carrying out insulation work in the last 10 years. The percentage is 57 % for heating and ventilation measures and 24 % for installing a solar thermal or photovoltaic system.

Table 3 presents summary statistics on the financial characteristics of homeowners and landlords. In the questionnaires, respondents were asked to indicate their monthly net household income in one of 21 given categories, ranging from less than 500 euros to 10,000 euros or more. We use the midpoint for each category and one and a half times the lower bound for the top category (e.g., Feldman, 2010) to calculate the equivalized monthly net household income. Equivalized household income accounts for household size and is based on the modified OECD equivalence scale (Hagenaars et al., 1994). On this scale, the first adult in a household is weighted by a factor of 1, additional adults by 0.5, and children under 14 by 0.3. On average, homeowners have an equivalized monthly net household income of €2,210. The average income of landlords is slightly higher, at €2,570.

From the equivalized monthly net household income, we derived the variable '*low income*'. This variable takes the value one if the equivalized monthly net household income is less than 60 % of the median equivalized monthly net income of the overall population. This threshold is known as the at-risk-of-poverty threshold, which amounted to €1,246 in Germany in 2022 (Statistisches Bundesamt, 2025). 17 % of the homeowners and 13 % of the landlords in our sample are identified as having a low income.

We also asked respondents whether they are currently paying back a loan or mortgage. In both groups, nearly half reported having an active loan or mortgage. The variable '*poor capital access*' takes the value one if respondents indicate that their access to loans, credit, or capital is rather poor or very poor on a five-point Likert scale. 10 % of the homeowners and 6 % of the landlords rated their access as rather or very poor. Similarly, we asked respondents to rate their current financial burden related to their home or rental property as low or high on a five-point Likert scale. The variable '*high financial burden*' takes the value one if respondents indicated a high or very high financial burden. About 33 % of the homeowners and 20 % of the landlords indicated a high or very high financial burden.

Finally, to measure debt aversion, we asked respondents to indicate their level of agreement with the following seven debt-related statements based on the work of Schleich et al. (2021): (i) "If I have debts, I like to pay them as soon as possible", (ii) "If I have debts, I prefer to delay paying them if possible, even if it means paying more in total", (iii) "If I have debts, it makes me feel uncomfortable", (iv) "If I have debts, it doesn't bother me", (v) "I dislike borrowing money", (vi) "I feel OK borrowing money for 'essential' purchases, e.g., cars, appliances, mortgage", (vii) "I enjoy being able to borrow money to buy things I like and to pay for things I cannot afford". In the case of statements (i), (iii), and (v) each ordinal variable takes the value one (two, three, four, five) if the respondent selected "totally disagree" ("rather disagree", "undecided", "rather agree", "totally agree"). In the case of statements (ii), (iv), (vi), and (vii)) the ordinal variables are constructed in reverse; that is, they take the value one (two, three, four, five) if the respondent selected "totally agree" ("rather agree", "undecided", "rather disagree", "totally disagree") for the corresponding statement. The variable '*high debt aversion*' takes the value one if the average value of the ordinal variables is at least four. In other words, the variable '*high debt aversion*' takes the value one if the sum of the seven statement variables is equal to or greater than twenty-eight. In both groups, more than half reported a high aversion to debt: 57 % of the homeowners and 53% of the landlords.

Table 3: Financial characteristics of homeowners and landlords

Variables	Homeowners			Landlords		
	Mean	Std. dev.	Min-Max	Mean	Std. dev.	Min-Max
Eq. monthly net household income in 1.000 Euro	2.21	1.28	0.1-15	2.57	1.70	0.1-15
Low income	0.17	0.38	0-1	0.13	0.33	0-1
Loan or mortgage payments	0.45	0.50	0-1	0.47	0.50	0-1
Poor capital access	0.10	0.30	0-1	0.06	0.24	0-1
High financial burden	0.33	0.47	0-1	0.20	0.40	0-1
High debt aversion	0.57	0.50	0-1	0.53	0.50	0-1
Number of respondents	1,752			859		

2.2. Experimental design

We elicited the preferences of homeowners and landlords for energy retrofits via a stated choice experiment. The design of the experiment followed Lang et al. (2021) and consisted of multiple treatments in a within- and between-subject design, with a total of twelve choice tasks per participant. However, in this study, only the first six choice tasks without any treatments are used for the analysis.[2]

At the beginning of the choice experiment, all participants received detailed and identical information about the hypothetical choice situation.[3] In each choice task, respondents were asked to choose between three retrofit options and one no-retrofit option, the so-called opt-out option. The retrofit options were specified by six attributes that can be divided into

[2]In the treatment design, participants received varying additional information after the first six choice tasks and then responded to six additional choice tasks. The analysis and results of the treatment part of the experiment will be presented in a separate study.

[3]The full text of the experiment, translated into English, can be found in Appendix A.

three categories: economic, technical, and ecological. An overview of the selected attributes and their levels is presented in Table 4, and an exemplary choice task translated into English is presented in Table 5.

Table 4: Attributes and attribute levels in the stated choice experiment

Attribute	Level
Heating system replacement	Gas heating; Gas with solar thermal heating; Pellet heating; Heat pump; No replacement
Scope of insulation measures	Low; Medium; High; No insulation measures
Investment costs (shown in €)	70 %; 85 %; 100 %; 115 %; 130 % of option- and respondent-specific investment costs.
Investment cost subsidy (shown in €)	0 %; 20 %; 40 %; 60 %; 80 % of investment costs.
Heating and hot water costs 2022 (shown in €)[a]	15 %[c]; 25 %[c]; 35 %[c,d]; 55 %[d]; 75 %[d,e]; 85 %[e]; 95 %[e]; 100 %[f] of respondent-specific stated or calculated cost without carbon emission costs.
Net cold rent 2022 (shown in €)[b]	+0 %; +1 %; +3 %; +5 %; +7 % +9 % of investments costs minus investment costs subsidy.
Annual CO_2 emissions (shown in tons)	15 %[c]; 25 %[c]; 35 %[c,d]; 55 %[d]; 75 %[d,e]; 85 %[e]; 95 %[e]; 100 %[f]

Note: [a]This attribute was only shown in the choice tasks for the homeowner sample. [b]This attribute was only shown in the choice tasks for the landlord sample. [c]If option-specific scope of insulation measure is 'high'. [d]If option-specific scope of insulation measure is 'medium'. [e]If option-specific scope of insulation measure is 'low'. [f]If option-specific scope of insulation measure is 'no insulation measures'.

The first attribute, '*heating system replacement*', belonged to the technical category and had five levels. It offered the replacement of the existing heating system with a gas heating system, a gas with solar thermal heating system, a pellet heating system, or a heat pump. The option to not replace the heating system was also available. For the opt-out option, the no replacement level was always shown.

The second attribute, '*scope of insulation measures*', was also technical in nature and had four levels. The attribute referred to the extent of insulation measures that could be applied to the building and was classified as low, medium, high, and no insulation measures. The no insulation measures level was always shown in the opt-out option.

The first economic attribute that we included was the third attribute, '*investment costs*'. It reflected the total amount to be paid for the corresponding retrofit option and was shown in euros. Naturally, for the opt-out option, the investment cost was zero. To ensure realism in the values shown for the retrofit options, we calculated these values on an option- and respondent-specific basis. That is, we considered different investment costs depending on the type of heating system replacement and the scope of the insulation measures within a specific option. These investment costs also varied with the type of building and the living space reported by the respondents in the previous survey questions. Thus, we calculated option-specific and respondent-specific investment costs depending on the option and the individual respondent, and then multiplied them by one of the five attribute levels: 70 %, 85 %, 100 %, 115 %, and 130 %. The resulting investment costs were rounded to the nearest 100 euros in the choice tasks presented. The investment costs considered for the different heating systems, the scope of insulation measures, and the types of building are presented in Table B.1 in Appendix B.

Table 5: Exemplary choice task (translated)

Attributes	Option 1	Option 2	Option 3	No energy retrofit
Heating system replacement	No replacement	Gas heating	Pellet heating	No replacement
Scope of insulation measures	Low	Medium	High	No insulation measure
Investment costs	22.500 €	51.400 €	89.700 €	0 €
Investment cost subsidy	9.000 €	0 €	17.900 €	0 €
Heating and hot water costs 2022[a]	720 €	530 €	240 €	960 €
Net cold rent 2022[b]	11.160 €	11.150 €	10.970 €	10.800 €
Annual CO_2 emissions	3.9 t	2.2 t	0.1 t	5.3 t
I choose	☐	☐	☐	☐

Note: [a]This attribute was only shown in the choice tasks for the homeowner sample. [b]This attribute was only shown in the choice tasks for the landlord sample.

The fourth attribute, '*investment cost subsidy*', was the second economic attribute and related to the subsidies granted for the corresponding retrofit option. It included five levels, namely 0 %, 20 %, 40 %, 60 %, and 80 % of the investment costs, and was also expressed in euros, rounded to the nearest 100 euros. The value of the opt-out option was zero.

For the homeowner sample, the fifth attribute, '*heating and hot water costs 2022*', was the third economic attribute. It refers to the heating and hot water costs to be paid in 2022. Since many households in Germany receive their heating and hot water bills only once a year and up to 12 months after the year of consumption, we asked respondents to report their heating and hot water costs for either the year 2020 or 2021. If respondents reported their heating and hot water costs for the year 2020, these costs were displayed in the opt-out option. For the retrofit options, we multiplied these costs by one of the eight attribute levels. The levels applied varied according to the option-specific depth of insulation (no insulation, low, medium, high) and ranged from 15 % to 100 %. This takes into account the potential energy savings and, therefore, potential cost savings that result from a given scope of insulation measures. If respondents reported their heating and hot water costs for the year 2021, the procedure was identical, except that we subtracted the costs of carbon emissions from the reported costs to obtain a comparable cost indicator. This was necessary because Germany implemented a CO_2 price of €25 per ton on fossil fuels in 2021. The CO_2 emission costs were calculated based on the emission factors of the reported heating system, building type, construction year, and living space. Finally, if the respondents did not report their heating and hot water costs, we estimated them using the reported building type, construction year, heating system, living space, and an assumed heating price of six cents per kilowatt-hour (Statistisches Bundesamt, 2023). In the presented choice tasks, the resulting heating and hot water costs were rounded to the nearest 10 euros. The considered heat consumption levels and emission factors related to the different building types, construction years, and heating systems are presented in Tables B.2 and B.3 in Appendix B.

Since landlords do not pay the heating and hot water costs of a rented apartment or house, but can realize an increase in the rent charged with an energy retrofit, the fifth attribute was not '*heating and water costs 2022*' but '*net cold rent 2022*' in the choice experiment for the landlord sample. If respondents reported the net cold rent they received in 2022, this rent was displayed in the opt-out option. For the retrofit options, the reported rent was increased by an investment-dependent premium. The premium consisted of the investment costs minus the investment costs subsidy of the choice option, multiplied by one of the six attribute levels, ranging from 0 % to 9 %. If respondents did not report the net cold rent they received in 2022, we calculated it based on the reported living space and the average net cold rent per square meter at the federal state level. All rent values were rounded to the nearest 10 euros in the choice tasks presented.

Finally, the sixth attribute, '*annual CO_2 emissions*', belonged to the ecological category and indicated the annual CO_2 emissions related to the heating and hot water supply of the apartment or house. CO_2 emissions were calculated based on the emission factors of the option-specific heating system and the reported building type, construction year, and living space. For the retrofit options, these emissions were multiplied by one of the eight attribute levels. As with the '*heating and hot water costs*' attribute, the applied levels varied according to the option-specific depth of insulation (no insulation, low, medium, high) and ranged from 15 % to 100 %, taking into account the potential emission savings resulting from a given insulation measure. The values displayed were rounded to one decimal place in tons per year. Exemplary choice tasks in German, as shown to homeowners and landlords, are provided in Figures A.2 and A.3 in Appendix A.

2.3. Econometric approach

In our econometric approach, we follow a three-step procedure. First, we analyze the likelihood of choosing an energy retrofit by examining the frequency with which participants selected a retrofit option instead of the no-retrofit option across the six choice tasks. This frequency, ranging from zero to one, is analyzed using fractional probit regressions that include the individual characteristics discussed in Section 2.1 as explanatory variables.

In the second step, we analyze the stated choice experiment in more detail based on the random utility maximization theory developed by McFadden (1974). According to this theory, it is assumed that participants will choose a particular retrofit option within a choice situation if the utility associated with this option is greater than that of all the remaining options. For the homeowner sample, the utility U_{njt} that participant n ($n = 1, ..., N$) receives from choosing option j ($j = 1, ..., 4$) in choice situation t ($t = 1, ..., 6$) can be expressed as:

$$\begin{aligned} U_{njt} = {} & \beta_{n,gas} gas_{njt} + \beta_{n,gassolar} gassolar_{njt} + \beta_{n,pellet} pellet_{njt} + \beta_{n,heatpump} heatpump_{njt} \\ & + \beta_{n,low} low_{njt} + \beta_{n,medium} medium_{njt} + \beta_{n,high} high_{njt} \\ & + \beta_{n,investcost} investcost_{njt} + \beta_{n,subsidy} subsidy_{njt} + \beta_{n,heatingcost} heatingcost_{njt} \\ & + \beta_{n,emissions} emissions_{njt} + \beta_{n,noretrofit} noretrofit_{njt} + \varepsilon_{njt}, \end{aligned} \tag{1}$$

where the levels of the attribute '*heating system replacement*' are represented by the dummy variables '*gas*', '*gassolar*', '*pellet*', and '*heatpump*'. The reference category is '*no replacement*'. The levels of the attribute '*scope of insulation measures*' are defined by the dummy variables '*low*', '*medium*', and '*high*', with the reference level being '*no insulation measures*'. The continuous variables '*investcost*', '*subsidy*', and '*heatingcost*' represent the monetary attributes '*investment costs*', '*investment costs subsidy*', and '*heating and hot water costs 2022*', respectively. The continuous variable '*emissions*' represents the ecological attribute '*annual CO_2 emissions*'. Furthermore, the dummy variable '*noretrofit*' for the '*no retrofit*' option is included. $\beta_{nk}\,(k = 1, ..., K)$ are the unknown preference parameters to be estimated, and ε_{njt} is a stochastic error term that captures all unobserved factors. For the dummy-coded attributes, the estimated parameters reflect the change in utility relative to the corresponding reference level, while for the continuous variables, they reflect the change in utility related to a change in the corresponding attribute level of one unit.

Similarly, the utility function for the landlord sample can be expressed by replacing the continuous variable '*heating cost* and the corresponding preference parameter $\beta_{n,heatingcost}$ with the continuous variable '*rent*' and the preference parameter $\beta_{n,rent}$:

$$\begin{aligned} U_{njt} = {} & \beta_{n,gas} gas_{njt} + \beta_{n,gassolar} gassolar_{njt} + \beta_{n,pellet} pellet_{njt} + \beta_{n,heatpump} heatpump_{njt} \\ & + \beta_{n,low} low_{njt} + \beta_{n,medium} medium_{njt} + \beta_{n,high} high_{njt} \\ & + \beta_{n,investcost} investcost_{njt} + \beta_{n,subsididy} subsidy_{njt} + \beta_{n,rent} rent_{njt} \\ & + \beta_{n,emissions} emissions_{njt} + \beta_{n,noretrofit} noretrofit_{njt} + \varepsilon_{njt}. \end{aligned} \tag{2}$$

We apply the commonly used mixed logit models (e.g., McFadden and Train, 2000; Hensher and Greene, 2003) to estimate the unknown preference parameters. In contrast to multinomial logit models, mixed logit models do not rely on the restrictive IIA (independence of irrelevant alternatives) assumption, which states that choice probabilities between two alternatives are independent of other available alternatives. Furthermore, mixed logit models allow for heterogeneity in participants' preferences and can handle correlations between choice alternatives. This is particularly important in our case because participants made six sequential choices in a row (e.g., Gutsche and Ziegler, 2019; Kanberger and Ziegler, 2024).

The mixed logit models are estimated using simulated maximum likelihood (SML) estimation. As is common practice, one financial parameter, in our case the parameter for the investment cost, is specified as fixed, and all other parameters are specified as random. The random parameters β_{nk} are assumed to be continuously distributed across n (e.g., Greene, 2019; Gutsche and Ziegler, 2019):

$$\beta_{nk} = \beta_k + \sigma_k u_{nk}, \tag{3}$$

where the standard deviation of the distribution of β_{nk} around the mean β_k is represented by σ_k, and the individual-specific heterogeneity in preferences is captured by $u_{nk} \sim N(0, 1)$.

This approach enables us to estimate the mean marginal willingness to pay (WTP) for each attribute (level) by the negative of the ratio of the estimated mean of the corresponding random parameter to the estimated fixed parameter of the investment costs (Hole, 2007a,b):

$$WTP_k = -\frac{\beta_k}{\beta_{investcost}}. \tag{4}$$

Finally, in the third step of our analysis, we use a mixed logit model with interaction terms between individual financial characteristics and the no-retrofit option, as well as the investment cost subsidy, to examine the relevance of individual financial characteristics in more detail.

3. Results

In this section, we present the estimation results from our three-step econometric approach. First, we present and discuss the results regarding the likelihood of choosing an energy retrofit to examine the relationship between individual characteristics and choice frequency. Secondly, we present and discuss the results of the mixed logit estimation concerning preferences and WTP for the technical, economic, and ecological characteristics of specific energy retrofits. Finally, based on an extended mixed logit model with interaction terms, we present and discuss the relevance of financial characteristics in this context.

3.1. Likelihood of choosing an energy retrofit

In the stated choice experiment, participants had six opportunities to choose an energy retrofit. Figure 1 presents the frequency of choosing an energy retrofit by homeowners and landlords. In particular, the respondents can be divided into types of decision makers who always selected an energy retrofit and those who did not select an energy retrofit in each choice situation. About 31.3 % of homeowners always choose an energy retrofit, while in contrast, 14.7 % never choose a retrofit. In comparison, 42.4 % of landlords always opted for an energy retrofit. There are considerably fewer, namely 9.7 %, who always rejected an energy retrofit.

Table 6 reports the descriptive statistics for the '*frequency*' of choice situations in which homeowners and landlords chose an energy retrofit, along with the shares of homeowners and landlords who '*always*' or '*never*' choose an energy retrofit. Homeowners choose an energy retrofit in 62.5 % of the choice situations. For landlords, the percentage is significantly higher at 72.8 %. Statistically significant differences are also shown for '*always*' and '*never*'

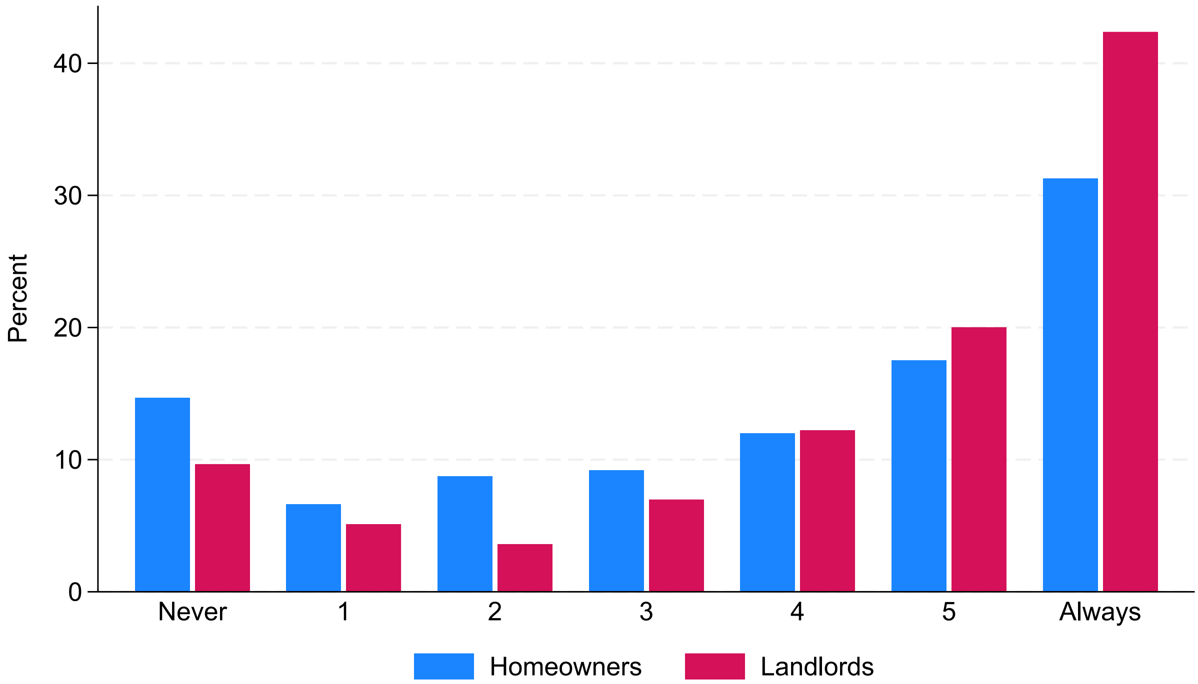

Figure 1: Frequency of energy retrofits choices

choosers, with landlords more often always and less often never choosing an energy retrofit in the six choice situations. Thus, landlords appear to be more open to carrying out energy retrofits than homeowners.

To gain a better understanding of which individual characteristics of homeowners and landlords are associated with energy retrofit choices, we estimated a fractional probit model incorporating an interaction between homeowner-landlord status and the sociodemographic, building, and financial characteristics outlined in Tables 1–3. Table 7 shows the estimated average discrete and marginal effects.[4] [5]

Regarding sociodemographics, we find that a 10-year increase in '*age*' is associated with a decrease of 6.2 percentage points in the frequency of energy retrofit choices among homeowners and a decrease of 3.1 percentage points among landlords on average. These effects are statistically significantly different from each other and indicate that older individuals,

[4] While we use the term '*effect*' as is common in econometric analysis, the relationships between '*frequency*' and the explanatory variables should be interpreted as correlations instead of causal effects.

[5] As a robustness check, we re-estimated the model using Ordinary Least Squares (OLS) regression. The results are consistent with the fractional probit estimates, confirming that the observed effects are not driven by the choice of the estimator.

Table 6: Descriptive statistics for energy retrofit choices

		Homeowners (N = 1,752)	Landlords (N = 859)	p-value
Frequency	Mean	0.625	0.728	$p < 0.001$
	Std. dev.	0.363	0.333	
Always	Mean	0.313	0.424	$p < 0.001$
	Std. dev.	0.464	0.494	
Never	Mean	0.147	0.097	$p < 0.001$
	Std. dev.	0.354	0.296	

Note: p-values refer to two-sample Mann-Whitney Wilcoxon (MWW) rank-sum test for differences across homeowners and landlords with respect to frequency of choices and two-sample Chi-squared test for differences across homeowners and landlords with respect to the share of 'always' and 'never' choosers.

particularly homeowners, are less likely to choose energy retrofits. This suggests that age-related factors, such as lower perceived benefits or higher risk aversion, may hinder retrofit adoption.

When it comes to building types and construction periods, we find statistically significant effects only for homeowners. Compared to homeowners living in multi-family houses with more than 13 apartments, homeowners living in detached or semi-detached houses with 1-2 apartments are, on average, 7.5 and 10.9 percentage points less likely to choose an energy retrofit, respectively. An explanation for this result could be that homeowners in single-family homes may perceive retrofits as less feasible or beneficial due to higher per-unit costs or a lower perceived return on investment. On the other hand, homeowners living in buildings constructed between 1979 and 2001 are, on average, 9.0 percentage points more likely to choose retrofits than those living in newer buildings constructed after 2015. This suggests that these older buildings may have a higher retrofit potential or a greater need for modernization. Furthermore, we find that homeowners with a pellet heating system are, on average, 12.3 percentage points less likely to choose an energy retrofit than homeowners with a night storage or other system.

Turning to prior experience with retrofits, our results indicate that homeowners who have previously carried out insulation, solar thermal, or PV retrofits are, on average, significantly more likely to choose an energy retrofit by 6.4 and 6.9 percentage points, respectively. For landlords, however, this only applies to those who have previously installed a solar thermal or PV system, with an average increase in energy retrofit choices of 9.7 percentage points. Nevertheless, these results suggest that previous experience with retrofits increases the likelihood of future implementation for both groups.

Table 7: Estimated average discrete and marginal effects for ‘frequency’ of energy retrofit choices

Variables	Homeowners		Landlords		Difference	
Sociodemographic characteristics:						
Age in 10-year increments	-0.062^{***}	(0.006)	-0.031^{***}	(0.009)	0.031^{***}	(0.011)
Female	0.027	(0.016)	0.007	(0.023)	−0.021	(0.028)
High education	0.025	(0.017)	0.018	(0.024)	−0.007	(0.029)
Household size	0.013	(0.008)	0.005	(0.010)	−0.008	(0.013)
Building characteristics:						
Detached house with 1-2 apartments	-0.075^{*}	0.037)	−0.025	(0.042)	0.049	(0.056)
Semi-detached house with 1-2 apartments	-0.109^{**}	(0.040)	0.004	(0.045)	0.113	(0.060)
Multi-family house with 3-12 apartments	0.015	(0.039)	0.004	(0.041)	−0.011	(0.056)
Construction period: before 1949	0.040	(0.045)	−0.035	(0.079)	−0.074	(0.090)
Construction period: 1949-1978	0.055	(0.042)	0.054	(0.076)	−0.002	(0.087)
Construction period: 1979-2001	0.090^{*}	(0.042)	0.036	(0.075)	−0.055	(0.085)
Construction period: 2002-2015	0.080	(0.042)	0.123	(0.076)	0.043	(0.087)
Heating system: oil	−0.021	(0.039)	0.096	(0.062)	0.117	(0.074)
Heating system: gas	0.016	(0.038)	0.098	(0.060)	0.082	(0.071)
Heating system: pellet	-0.123^{**}	(0.046)	−0.016	(0.084)	0.107	(0.096)
Heating system: heat pump	−0.042	(0.052)	−0.019	(0.087)	0.023	(0.101)
Heating system: district heating	−0.037	(0.047)	0.055	(0.065)	0.091	(0.080)
Good condition	−0.026	(0.019)	−0.007	(0.028)	0.019	(0.034)
Retrofit: Insulation	0.064^{***}	(0.018)	0.031	(0.027)	−0.034	(0.032)
Retrofit: Heating or ventilation	0.016	(0.017)	0.035	(0.026)	0.019	(0.031)
Retrofit: Solar thermal or PV	0.069^{**}	(0.022)	0.097^{***}	(0.027)	0.028	(0.035)
Financial characteristics:						
Low income	-0.058^{**}	(0.022)	0.019	(0.034)	0.077	(0.041)
Loan or mortgage in payments	−0.011	(0.017)	−0.013	(0.025)	−0.002	(0.030)
Poor capital access	-0.078^{**}	(0.029)	0.001	(0.045)	0.079	(0.054)
High financial burden	−0.020	(0.018)	−0.023	(0.029)	−0.003	(0.034)
High debt aversion	-0.058^{***}	(0.017)	−0.032	(0.025)	0.026	(0.030)
Number of respondents	1,752		859			

Note: Estimates are derived from a fractional probit model. Column (4) represents the statistical comparison of average discrete and marginal effects between groups using the delta method. Robust standard errors in parentheses. * (**, ***) means that the corresponding estimated parameter is different from zero at the 10 % (5 %, 1 %) significance level, respectively.

Finally, with respect to financial characteristics, the results show that homeowners with '*low income*' and '*poor capital access*' are, on average, 5.8 and 7.8 percentage points less likely to choose an energy retrofit than homeowners with higher income or better access to capital, respectively. This result indicates that financial capabilities play a significant role in energy retrofit decisions among homeowners. Interestingly, for landlords, we do not find similar statistically significant results. This also applies to '*high debt aversion*'. Here, we find that among homeowners, '*high debt aversion*' is negatively associated with energy retrofit choices, decreasing their likelihood by 5.8 percentage points on average. This finding aligns with the findings of Schleich et al. (2021) and suggests that homeowners who are more risk-averse regarding debt are less likely to invest in energy retrofits, even with a high income or good access to capital.

3.2. Preferences and WTP for energy retrofits

Table 8 shows the parameter estimates and the mean WTP estimates in mixed logit models for the choice of energy retrofits by homeowners and landlords. Since the mean WTP is the negative ratio of the estimated mean of the corresponding random parameter to the estimated fixed parameter of '*investment costs*', the estimates are only shown if the estimated mean of the corresponding random parameter is statistically significant. Additionally, since investment costs are entered into the model in €10,000 units, the negative ratio must be multiplied by 10,000 to obtain the estimated mean WTP in euros.

Regarding '*heating system replacement*', the statistically significant mean parameters and mean WTP estimates indicate a strong rejection of *'gas heating'* by both groups. The relatively high estimated negative mean WTP is likely due to the influence of the 2022 German gas crisis caused by the Russian invasion of Ukraine at the beginning of that year. Homeowners also strongly reject *'pellet heating'* and *'gas with solar thermal heating'*, while landlords' estimated mean WTP for *'gas with solar thermal heating'* is positive. The highest mean WTP is estimated for *'heat pump'* in both groups. The estimated mean WTP for homeowners is around €17,500, while the corresponding value for landlords is much higher, at around €39,500. This difference may be at least partly due to the fact that homeowners must pay for the replacement of the heating system entirely on their own, whereas landlords can pass at least some of the costs onto tenants via increased rent.

With respect to the '*scope of insulation measures*', we find a clear preference among homeowners, with the estimated mean WTP significantly increasing from around €21,200 for *'low'* insulation measures to around €46,400 for *'high'* insulation measures. This result suggests a strong belief among homeowners that insulation is a fundamental energy retrofit

Table 8: Estimation results for preferences and WTP for energy retrofits

	Homeowners			Landlords		
	Mean of the parameter	Std. dev. of the parameter	Mean WTP	Mean of the parameter	Std. dev. of the parameter	Mean WTP
Heating system replacement (*reference level: no replacement*):						
Gas heating	−1.034***	1.581***	−63,573	−0.487***	−0.890***	−47,869
	(−8.96)	(11.85)		(−4.21)	(−5.83)	
Gas with solar thermal heating	−0.157*	1.344***	−9,629	0.178*	−0.937***	17,491
	(−1.93)	(13.88)		(1.88)	(−7.83)	
Pellet heating	−0.623***	1.668***	−38,291	−0.183	1.840***	–
	(−5.58)	(12.91)		(−1.31)	(12.99)	
Heat pump	0.284***	1.707***	17,486	0.402***	1.513***	39,530
	(3.63)	(16.89)		(3.89)	(12.41)	
Scope of insulation measures (*reference level: no insulation*)						
Low	0.344***	0.413**	21,186	0.055	0.470***	–
	(3.95)	(1.99)		(0.56)	(2.77)	
Medium	0.591***	−0.341**	36,348	−0.008	−0.503***	–
	(4.92)	(−2.04)		(−0.06)	(−3.26)	
High	0.755***	−0.674***	46,415	−0.229	−0.561***	–
	(4.60)	(−4.79)		(−1.48)	(−2.92)	
Investment costs (in 10,000 Euro)	−0.163***	–	–	−0.102***	–	–
	(−11.31)			(−3.65)		
Investment cost subsidy (in 10,000 Euro)	0.120***	−0.123***	7,386	0.136***	0.145***	13,390
	(10.29)	(−5.02)		(5.42)	(4.69)	
Heating and hot water costs 2022 (in 1,000 Euro)	−0.421***	−1.511***	−2,587	–	–	–
	(−2.62)	(−8.50)				
Net cold rent 2022 (in 1,000 Euro)	–	–	–	−0.225	−2.409***	–
				(−0.48)	(−2.90)	
Annual CO_2 emissions (in tons)	−0.056*	0.436***	−3,444	−0.146***	0.491***	−14,390
	(−1.79)	(11.19)		(−2.50)	(7.64)	
No energy retrofit	0.346***	2.489***	21,308	−0.388***	2.424***	−43,272
	(3.40)	(21.92)		(−2.83)	(15.46)	
Number of respondents		1,752			859	
Number of choices		10,512			5,154	

Note: For the SML estimations, the user-written command 'mixlogit' (Hole, 2007b) in Stata and 1000 Haltons draws were used. Negative estimated standard deviations for the random parameters result from the SML estimation algorithm and can be interpreted as being positive (Hole, 2007b). Robust z-statistics in parentheses. * (**, ***) means that the corresponding estimated parameter is different from zero at the 10 % (5 %, 1 %) significance level, respectively.

measure, which is consistent with previous findings (e.g., Achtnicht and Madlener, 2014; Banfi et al., 2008). In contrast, we find no statistically significant preference for insulation measures among landlords because none of the estimated mean parameters for the *scope of insulation measures* are statistically significant at a common level. However, the standard deviations of the random parameters are highly significantly different from zero, indicating significant heterogeneity in preferences. The same applies to all other attributes in both groups.

Regarding the monetary cost and benefit attributes, *'investment costs'*, *'investment cost subsidy'*, and *'heating and hot water costs 2022'*, the estimated mean parameters and mean WTP are statistically significant, show the expected signs, and are consistent with standard economic theory and previous research (e.g., Achtnicht, 2011; Rouvinen and Matero, 2013). The statistically significant and negative estimated parameters for *'investment costs'* indicate that lower investment costs for energy retrofits are preferred by homeowners and landlords. Since the investment cost parameters are implemented in the model as fixed parameters, homogeneous preferences are assumed.

For both groups, we find a meaningful non-monetary effect of investment cost subsidies in the form of an additional WTP that goes beyond the direct monetary value of the subsidy itself. On average, homeowners and landlords are willing to pay around €7,400 and €13,400 more, respectively, for an energy retrofit per €10.000 of subsidy. This result is consistent with previous findings, e.g., Olsthoorn et al. (2017) and Schleich et al. (2021, 2022), and suggests that subsidies not only serve as a financial tool but can also increase the willingness to invest in energy retrofits via additional channels, such as reduced financial risk perception or increased trust in policy.

Turning to annual monetary benefits, the estimated statistically significant negative parameter for *'heating and hot water costs in 2022'* suggests that homeowners dislike higher annual heating and hot water costs. Reversing the interpretation of the estimated negative mean WTP for an increase in these costs, we find that, on average, homeowners would be willing to pay around €2,600 more for an energy retrofit that would reduce their annual heating and hot water costs by €1,000. From a purely economic perspective, this value may seem low. However, it is also likely to reflect non-monetary behavioral barriers, such as time discounting, present bias, and risk aversion. Homeowners likely tend to heavily discount future savings and overweight upfront costs. This is consistent with the broader literature on energy efficiency investments (e.g., Qiu et al., 2014; Schleich et al., 2019) Unfortunately, we cannot say anything similar about the preferences or WTP for annual monetary benefits in the landlord case, as the estimated parameter for *'net cold rent 2022'* is not statistically significant at any common level of significance.

For the ecological attribute *'annual CO_2 emissions'*, the statistically significant negative parameters for both homeowners and landlords indicate that both groups prefer lower emissions. On average, homeowners are willing to pay around €3,400 to avoid one ton of CO_2 emissions annually, while landlords are willing to pay around €14,400. Assuming a 20-year retrofit lifetime and constant annual emissions savings of one ton, this translates to an implicit valuation of approximately €170 per ton for homeowners and €720 per ton for landlords over the lifetime of the investment. Both values are well above the German carbon price of €30 per ton in 2022, suggesting that environmental values are strong, especially among landlords. However, since the respondents were informed about the rising carbon price up to 2026 before making their retrofit choices (see Figure A.1), the high estimated WTP may also reflect information effects that heightened the respondents' awareness and valuation of emissions reductions.

Finally, the positive and significant parameter for the *'no energy retrofit'* option among homeowners indicates a strong preference for inaction, underscoring the challenge of overcoming inertia. In contrast, the negative parameter for landlords suggests that they are less likely to opt out, which reinforces the finding that landlords in our sample are more open to adopting retrofits.

3.3. Relevance of financial characteristics

To analyze the effects of individual financial characteristics on preferences for investment cost subsidies and for no energy retrofits in more detail, we estimated a second extended mixed logit model that includes interaction terms between individual financial characteristics and the investment cost subsidy attribute, as well as the no retrofit option. The estimation results are presented in Table 9.[6]

The results of the interaction model are largely consistent with those of the main model. The parameter for investment costs remains negative and highly significant for both homeowners and landlords, confirming that higher upfront costs reduce the likelihood of opting for an energy retrofit. The average parameter for the investment cost subsidy is positive and highly significant for both groups, which again confirms the non-monetary value of subsidies beyond their direct financial value. The associated WTP estimates of around €6,700 for

[6] To conserve space, Table 9 only presents the parameters and WTP estimates for the *'investment costs'*, the *'investment cost subsidy'*, the *'no energy retrofit'* option, and the interaction terms. The full model results are reported in Table B.4 in Appendix B.

Table 9: Estimation results for preferences and WTP for energy retrofits of the interaction model

	Homeowners			Landlords		
	Mean of the parameter	Std. dev. of the parameter	Mean WTP	Mean of the parameter	Std. dev. of the parameter	Mean WTP
Investment costs (in 10,000 Euro)	-0.162^{***}	–	–	-0.099^{***}	–	–
	(-11.15)			(-3.42)		
Investment cost subsidy (in 10,000 Euro)	0.109^{***}	-0.114^{***}	$6,702$	0.123^{***}	0.146^{***}	$12,396$
	(5.11)	(-4.29)		(3.59)	(4.71)	
Investment cost subsidy						
x low income	-0.038	–	–	-0.020	–	–
	(-1.38)	–		(-0.41)	–	
x loan or mortgage payments	0.011	–	–	0.015	–	–
	(0.53)	–		(0.58)	–	
x poor capital access	-0.034	–	–	-0.004	–	–
	(-0.93)	–		(-0.06)	–	
x high financial burden	0.038^{*}	–	$2,356$	0.006	–	–
	(1.84)	–		(0.15)	–	
x high debt aversion	0.008	–	–	0.021	–	–
	(0.39)	–		(0.77)	–	
No energy retrofit	-0.201	2.432^{***}	–	-0.752^{***}	2.401^{***}	$-75,641$
	(-1.14)	(20.71)		(-3.15)	(15.74)	
No energy retrofit						
x low income	0.515^{**}	–	$31,782$	-0.123	–	–
	(2.39)	–		(-0.38)	–	
x loan or mortgage payments	-0.070	–	–	0.051	–	–
	(-0.42)	–		(0.22)	–	
x poor capital access	0.641^{**}	–	$39,565$	0.235	–	–
	(2.31)	–		(0.52)	–	
x high financial burden	0.082	–	–	-0.103	–	–
	(0.48)	–		(-0.37)	–	
x high debt aversion	0.683^{***}	–	$42,190$	0.631^{***}	–	$63,481$
	(4.21)	–		(2.71)	–	
Number of respondents		1,752			859	
Number of choices		10,512			5,154	

Note: For the SML estimations, the user-written command 'mixlogit' (Hole, 2007b) in Stata and 1000 Haltons draws were used. Negative estimated standard deviations for the random parameters result from the SML estimation algorithm and can be interpreted as being positive (Hole, 2007b). Robust z-statistics in parentheses. * (**, ***) means that the corresponding estimated parameter is different from zero at the 10 % (5 %, 1 %) significance level, respectively.

homeowners and €12,400 for landlords per €10,000 in subsidies are lower than in the main model, which is to be expected since the interaction terms absorb part of the average subsidy effect.

Examining the interaction terms between individual financial characteristics and the investment cost subsidy reveals that the interaction with '*high financial burden*' is positive and statistically significant for homeowners. This suggests that homeowners who perceive a higher financial burden derive greater non-monetary benefits from the subsidies than those with a lower burden. We do not observe a similar effect for landlords, and all other interaction terms with the investment cost subsidy are statistically insignificant for both groups.

Regarding the '*no energy retrofit*' option, the mean parameter for homeowners is insignificant in the interaction model, contrasting with the positive and significant estimate in the main model. This shift likely reflects the fact that the interaction terms capture some of the inertia previously attributed to the '*no energy retrofit*' option itself. Indeed, the interactions of the 'no energy retrofit' option with '*low income*', '*poor capital access*' and '*high debt aversion*' are positive and statistically significant for homeowners. This suggests that homeowners with low income, poor access to capital, or high debt aversion have a significantly stronger preference for inaction. This supports the view that financial constraints and psychological barriers to borrowing are the main reasons for avoiding energy retrofits. For landlords, however, only the interaction with '*high debt aversion*' is statistically significant and positive. This suggests that landlords who are highly averse to debt are also significantly more likely to forego energy retrofits, despite landlords generally being more open to energy retrofits, as shown by the main model.

Taken together, the results of the interaction model indicate that debt aversion is a primary barrier to retrofit adoption for both groups, while low income and poor access to capital additionally constrain homeowners. The effectiveness of subsidies as a policy instrument, on the other hand, is amplified specifically for financially burdened homeowners. These results highlight the importance of tailoring policy instruments to the financial situation of the target group, rather than applying uniform subsidy programs.

4. Conclusion and policy implications

Decarbonizing the residential building sector fundamentally depends on understanding the complex decision-making processes of private property owners. By evaluating 1,752 homeowners and 859 landlords within a unified, individualized choice experiment, this study provides empirical insights into how technical preferences, financial constraints, and policy designs interact to shape retrofit decisions.

The empirical results show that landlords in our sample exhibit a generally higher propensity to retrofit than homeowners. Homeowners express a strong preference for high insulation levels and heat pumps, along with a pronounced aversion to fossil fuel heating systems; a pattern likely amplified by acute energy security concerns during the 2022 gas crisis. Crucially, the findings reveal that investment subsidies generate substantial non-monetary value beyond their direct financial transfer by serving as risk-reducing mechanisms that enhance decision-making confidence. Together with the finding that debt aversion, low income, and limited access to capital impose significant barriers to adoption, these results highlight that policy effectiveness depends as much on reducing perceived investment risk and administrative friction as it does on the absolute magnitude of financial transfers.

These insights have several key implications for designing energy policies. First, since subsidies provide non-monetary value as risk-reduction instruments, program evaluation should extend beyond direct fiscal efficiency and prioritize administrative simplicity, transparent structuring, and clear communication. These factors can encourage greater participation than complex transfers of equal monetary value. Second, since debt aversion is a significant barrier for homeowners and landlords alike, policymakers should emphasize financing instruments that eliminate or minimize the need for traditional bank loans, such as government-subsidized, low-interest loan programs with deferred repayment options. Third, direct grants are likely to be more effective than credit-based instruments for homeowners with low income or limited access to capital, as this group exhibits a significantly stronger tendency toward inaction. Fourth, since subsidies are particularly effective for homeowners who perceive a high financial burden, needs-based or tiered subsidy programs could increase the overall cost-effectiveness of energy retrofit subsidy programs by providing higher grants to households with limited financial resources and focusing support where behavioral and financial barriers are greatest.

Although these policy implications can be clearly derived from our empirical findings, some limitations of our study should also be considered. Most notably, the discrete choice experiment elicits hypothetical choices rather than actual market behavior, exposing the WTP estimates to potential hypothetical bias. Although we implemented explicit mitigating measures, including individualized cost baselines and reminders regarding personal budget constraints, some degree of overestimation cannot be ruled out.

Furthermore, the external validity of our results is limited by temporary contextual factors. The survey was conducted between July and November 2022, a period marked by the Russian invasion of Ukraine and the most critical phase of the 2022 German gas crisis. This macroeconomic backdrop likely amplified the observed aversion to gas heating systems. While subsequent geopolitical and market developments have sustained high energy prices and prolonged supply uncertainties for fossil fuels, the extreme volatility that characterized our field phase may limit the external validation of these specific heating preference parameters in more stable periods.

In addition to these temporal factors, there is a significant asymmetry regarding the representativeness of our samples. While the sample of homeowners was compiled using strict quota sampling to reflect the German homeowner population, the sample of landlords was recruited on a best-efforts basis due to the low incidence of landlords in the general population. This non-probability sampling approach introduces a likely self-selection bias, where landlords with an intrinsic interest in sustainability or property management were more likely to participate. This selection effect is supported by our descriptive statistics, which reveal higher historical retrofit rates among the participating landlords than among the homeowners. Consequently, the finding that landlords exhibit a higher probability of choosing a retrofit applies specifically to this proactive sample and should not be generalized to the broader, highly heterogeneous population of German landlords.

Future research should address several of these limitations. Revealed preference data on actual retrofit decisions, combined with stated preference data, would allow for a more precise assessment of the extent of hypothetical bias and provide a more complete picture of the drivers of retrofit adoption. Furthermore, a crucial direction for future research lies in explicitly modeling the interactive decision-making process between landlords and tenants. Germany features the highest tenant share in the European Union. Therefore, it is essential to investigate the landlord-tenant split incentive, information asymmetries, and the distributional consequences of rent increases resulting from energy retrofits in order to unlock the decarbonization potential of the residential sector.

Declaration of Generative AI and AI-assisted technologies in the manuscript preparation process: During the preparation of this work, the authors used ChatGPT and DeepL Write to assist with phrasing, refining the language, and structuring the sentences. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Funding: This work was funded by the German Federal Ministry of Education and Research (grant number: 01LA1808B)

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Appendix A. Description of the choice experiment -translated from German-

Next, we will move on to a specific section of the survey that focuses on energy retrofits for your apartment or house [rental apartment][7]. Please imagine that you would like to retrofit the energy efficiency of your home [rental apartment]. We will present three different retrofit options for you to choose from six times in a row. The options differ in certain characteristics. If none of the three options appeal to you, you also have the option of choosing none of the retrofit options.

Please take your time to read through the following information; after 15 seconds, you can. After 15 seconds, you can click on 'continue'.

The available retrofit options differ in six characteristics.

Heating system replacement
The existing heating system is replaced with one of the following heating systems: gas heating, gas heating with solar thermal energy, pellet heating, or heat pump. No heating system replacement is also possible.

Scope of insulation measures
Possible measures include insulating the exterior facade, the roof, the basement ceiling, and/or the top-floor ceiling, as well as replacing the windows. The resulting scope of individual or combined insulation measures is classified as low, medium, or high. Depending on the scope of the insulation measures, energy and CO_2 emissions are reduced. No insulation measures, and thus no savings in energy and greenhouse gas emissions, are also possible.

Investment costs
The investment costs indicate the total amount to be paid for the energy retrofit. This includes all costs (materials, labor, etc.). The investment costs are calculated based on the information you have already provided about your apartment or house [rental apartment].

[7] Modifications for landlords are in square brackets.

Investment cost subsidy
The investment cost subsidy indicates the amount that you will receive as a public subsidy for the energy retrofit. The subsidy reduces the investment costs you have to pay yourself.

Heating and hot water costs 2022
The heating and hot water costs 2022 indicate the amount you will have to pay for heating and hot water in your apartment or house in 2022. These costs are calculated based on the information you have already provided about your apartment or house. CO_2 costs are not included.

[**Net cold rent 2022**]
[The net cold rent 2022, represents the income you will generate in 2022 from renting out your apartment after deducting all cold and hot utility costs. By investing in an energy retrofit, the net cold rent can be increased by passing on a portion of the investment costs to the tenant.]

Annual CO_2 emissions
The annual CO_2 emissions are caused by the heating and hot water supply of your apartment or house [rental apartment]. The emissions are calculated based on the information you have already provided about your apartment or house [rental apartment].

Assume that all retrofit options are technically and contractually feasible. Imagine that a gas connection is available. If you are currently carrying out a retrofit, assume the condition prior to the retrofit. The retrofit will begin over the course of the next 12 months.

On January 1, 2021, a CO_2 price for fossil fuels was introduced in Germany. In 2021, one ton of CO_2 cost 25 euros, and in 2022, one ton of CO_2 cost 30 euros.

This price will gradually increase to 65 euros by 2026. The figure below shows the CO_2 price development per ton up to 2026.

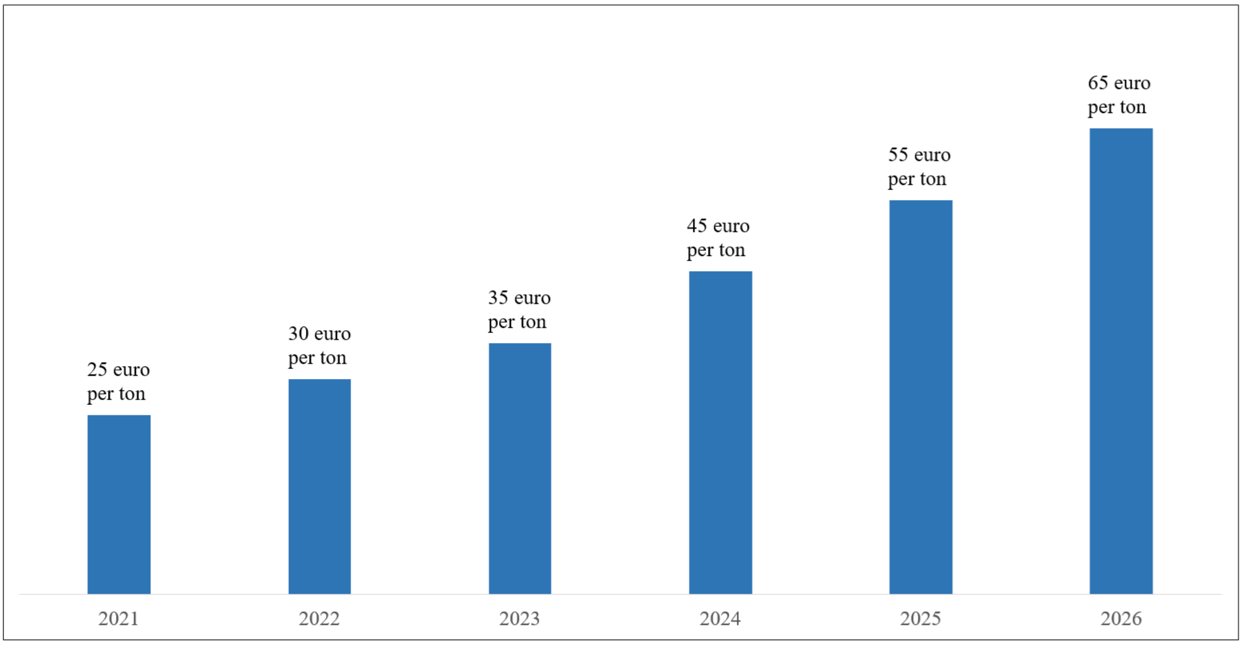


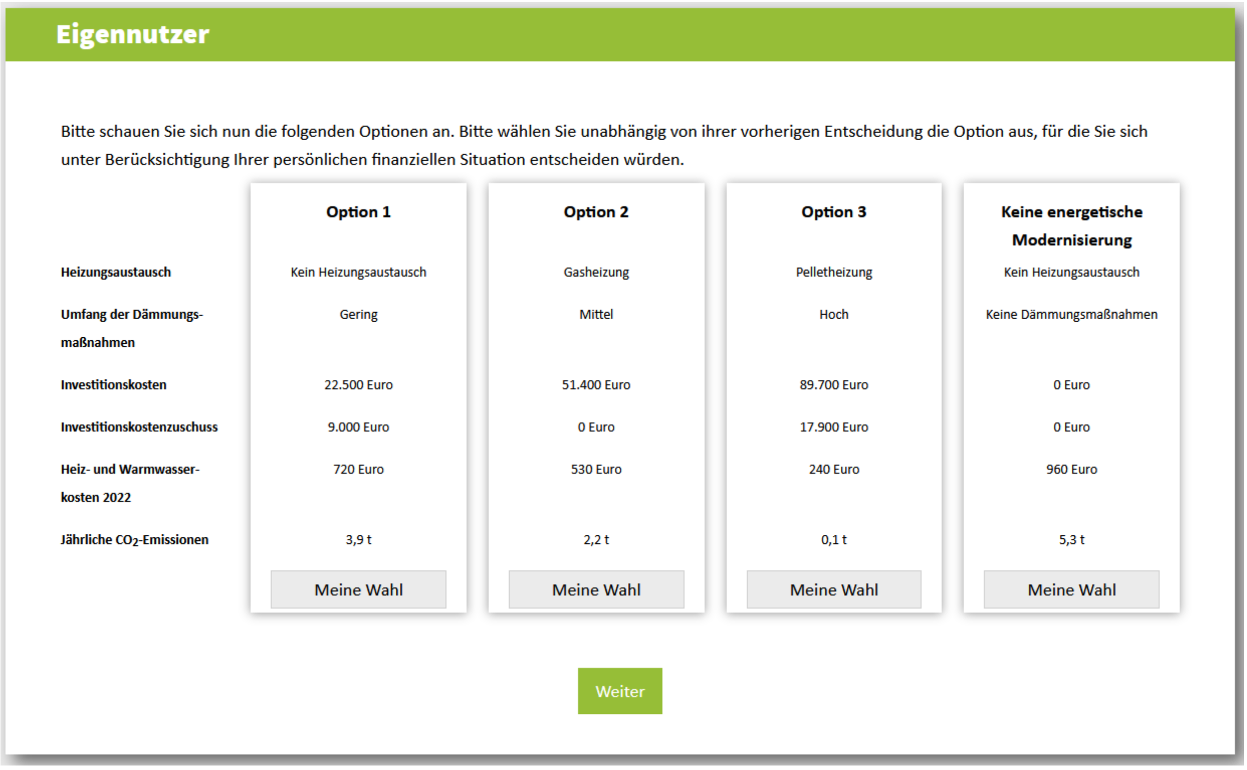
Figure A.1: Baseline CO_2 development

Now, please take a close look at each of the three energy retrofit options on the following six pages and select the option you would actually implement. If you do not wish to implement any of the three options, please select the option "No energy retrofit".

The information collected through this survey will be used to make recommendations for policy-making processes and to develop concrete proposals for a legal framework. We therefore ask that you select a retrofit option only if you would actually implement it. When making your decision, please keep in mind that you would have to forgo other things, as you would actually have to bear the costs of the retrofit. We therefore ask that you take your personal financial situation into account when making any decision.

Please note, however, that when making your choice, you should not take into account future trends in energy prices resulting from the war in Ukraine. Instead, use the values provided, particularly for heating and hot water costs in 2022. [8]

[8]The last sentence was not shown to the landlords.



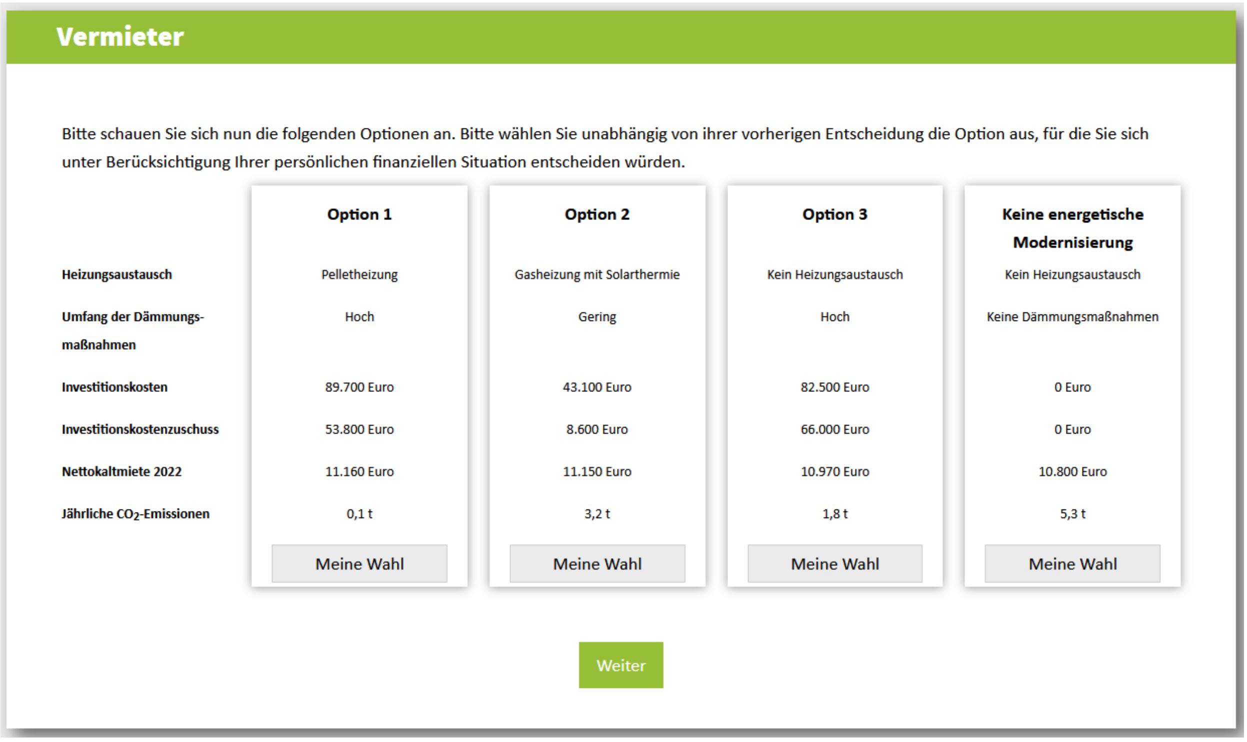
Eigennutzer

Bitte schauen Sie sich nun die folgenden Optionen an. Bitte wählen Sie unabhängig von ihrer vorherigen Entscheidung die Option aus, für die Sie sich unter Berücksichtigung Ihrer persönlichen finanziellen Situation entscheiden würden.

	Option 1	Option 2	Option 3	Keine energetische Modernisierung
Heizungsaustausch	Kein Heizungsaustausch	Gasheizung	Pelletheizung	Kein Heizungsaustausch
Umfang der Dämmungs-maßnahmen	Gering	Mittel	Hoch	Keine Dämmungsmaßnahmen
Investitionskosten	22.500 Euro	51.400 Euro	89.700 Euro	0 Euro
Investitionskostenzuschuss	9.000 Euro	0 Euro	17.900 Euro	0 Euro
Heiz- und Warmwasser-kosten 2022	720 Euro	530 Euro	240 Euro	960 Euro
Jährliche CO_2-Emissionen	3,9 t	2,2 t	0,1 t	5,3 t
	Meine Wahl	Meine Wahl	Meine Wahl	Meine Wahl

Weiter

Figure A.2: Exemplary choice set of homeowner sample (in German)



Vermieter

Bitte schauen Sie sich nun die folgenden Optionen an. Bitte wählen Sie unabhängig von ihrer vorherigen Entscheidung die Option aus, für die Sie sich unter Berücksichtigung Ihrer persönlichen finanziellen Situation entscheiden würden.

	Option 1	Option 2	Option 3	Keine energetische Modernisierung
Heizungsaustausch	Pelletheizung	Gasheizung mit Solarthermie	Kein Heizungsaustausch	Kein Heizungsaustausch
Umfang der Dämmungs-maßnahmen	Hoch	Gering	Hoch	Keine Dämmungsmaßnahmen
Investitionskosten	89.700 Euro	43.100 Euro	82.500 Euro	0 Euro
Investitionskostenzuschuss	53.800 Euro	8.600 Euro	66.000 Euro	0 Euro
Nettokaltmiete 2022	11.160 Euro	11.150 Euro	10.970 Euro	10.800 Euro
Jährliche CO_2-Emissionen	0,1 t	3,2 t	1,8 t	5,3 t
	Meine Wahl	Meine Wahl	Meine Wahl	Meine Wahl

Weiter

Figure A.3: Exemplary choice set of landlord sample (in German)

Appendix B. Additional tables

Table B.1: Considered costs for the investment costs attribute

Attribute & Level	Single home	Building with 3-12 apartments	Building with 13 or more apartments
Heating system replacement			
Gas heating	€8,000	€5,500	€4,000
Gas with solar thermal heating	€15,000	€10,500	€7,500
Heat pump	€20,000	€14,000	€10,000
Pellet heating	€23,000	€16,000	€11,500
No replacement	€0	€0	€0
Scope of the insulation measures			
Low	€225/m^2	€160/m^2	€115/m^2
Medium	€525/m^2	€370/m^2	€265/m^2
High	€825/m^2	€580m^2	€415/m^2
No insulation measure	€0/m^2	€0/m^2	€0/m^2

Note: The investment cost values for the different heating systems and insulation levels are derived from Achtnicht (2011), co2online (2021),Oberegger et al. (2020), Staniaszek et al. (2015), and Walberg et al. (2022).

Table B.2: Building classes

Class	Building type	Construction period	Heat demand
1	Single home	until 1948	235.7 kWh/m^{2}a
2	Semi-detached home	until 1948	173.6 kWh/m^{2}a
3	Building with 3-12 apartments	until 1948	184.6 kWh/m^{2}a
4	Building with 12 or more apartments	until 1948	124.8 kWh/m^{2}a
5	Single home	1949-1978	239.9 kWh/m^{2}a
6	Semi-detached home	1949-1978	168.4 kWh/m^{2}a
7	Building with 3-12 apartments	1949-1978	150.5 kWh/m^{2}a
8	Building with 12 or more apartments	1949-1978	142.7 kWh/m^{2}a
9	Single home	1979-2001	169.8 kWh/m^{2}a
10	Semi-detached home	1979-2001	120.9 kWh/m^{2}a
11	Building with 3-12 apartments	1979-2001	132.2 kWh/m^{2}a
12	Building with 12 or more apartments	1979-2001	114.8 kWh/m^{2}a
13	Single home	2002-2015	95.9 kWh/m^{2}a
14	Semi-detached home	2002-2015	87.4 kWh/m^{2}a
15	Building with 3-12 apartments	2002-2015	75.6 kWh/m^{2}a
16	Building with 12 or more apartments	2002-2015	69.5 kWh/m^{2}a
17	Single home	from 2016	70.4 kWh/m^{2}a
18	Semi-detached home	from 2016	59.7 kWh/m^{2}a
19	Building with 3-12 apartments	from 2016	85.3 kWh/m^{2}a
20	Building with 12 or more apartments	from 2016	63.8 kWh/m^{2}a

Note: Buildings are classified into twenty classes based on the established building typologies of the European projects TABULA and EPISCOPE (Institut Wohnen und Umwelt, 2014). Heat demand is calculated for each class based on the principles set out in the DIN standards (DIN V 4108-6, DIN EN 12831 and DIN V 4701-10).

Table B.3: Emission factors of energy sources

Energy source	Emission factor
Heating oil	310 g CO_2 equivalent per kWh
Natural gas	240 g CO_2 equivalent per kWh
Natural gas heating with solar thermal	200 g CO_2 equivalent per kWh
Liquefied petroleum gas	270 g CO_2 equivalent per kWh
Hard coal, lignite, briquettes	415 g CO_2 equivalent per kWh
Wood, wood pellets	20 g CO_2 equivalent per kWh
Electricity for heat pumps	187 g CO_2 equivalent per kWh
Electricity for direct heating (e.g., night storage heaters)	560 g CO_2 equivalent per kWh
District heating using primarily fossil fuels	350 g CO_2 equivalent per kWh
District heating using primarily renewable energy sources	60 g CO_2 equivalent per kWh
Other	275 g CO_2 equivalent per kWh

Note: The emission factors are taken from the German Building Energy Act (GBEA) (Gebäudeenergiegesetz, 2020). The value for 'gas heating with solar thermal' was calculated using the GBEA emission factor for natural gas and a conservative installation size for solar thermal modules. The value for 'hard coal, lignite, briquettes' corresponds to the average value for hard coal and lignite specified in the GBEA. The value for 'electricity for heat pump' is the GBEA-given value for grid-based electricity divided by a conservative coefficient of performance (COP) of three. The value for 'district heating using primarily fossil fuels' is the average value specified in the GBEA for district heating networks operating using hard coal, lignite, or gaseous and liquid fuels. The 'other' value refers to the average value for heating oil and natural gas.

Table B.4: Estimation results for preferences and WTP for energy retrofits of the interaction model, full model results

	Homeowners			Landlords		
	Mean of the parameter	Std. dev. of the parameter	Mean WTP	Mean of the parameter	Std. dev. of the parameter	Mean WTP
Heating system replacement (*reference level: no replacement*):						
Gas heating	-1.035^{***}	1.568^{***}	$-63,871$	-0.493^{***}	-0.894^{***}	$-49,521$
	(-8.94)	(11.99)		(-4.33)	(6.36)	
Gas with solar thermal heating	-0.160^{**}	1.332^{***}	$-9,890$	0.173^{*}	0.938^{***}	$17,428$
	(-1.98)	(14.00)		(1.87)	(7.75)	
Pellet heating	-0.619^{***}	1.665^{***}	$-38,235$	-0.160	1.833^{***}	–
	(-5.29)	(12.29)		(-1.17)	(12.42)	
Heat pump	0.283^{***}	1.713^{***}	$17,466$	0.388^{***}	1.537^{***}	$38,980$
	(3.63)	(16.94)		(3.73)	(12.30)	
Scope of insulation measures (*reference level: no insulation*):						
Low	0.325^{***}	0.493^{***}	$20,078$	0.033	-0.458^{***}	–
	(3.75)	(3.38)		(0.34)	(-2.73)	
Medium	0.570^{***}	0.359^{*}	$35,163$	-0.049	0.502^{***}	–
	(4.74)	(1.85)		(-0.38)	(3.28)	
High	0.738^{***}	0.462	$45,537$	-0.281^{*}	-0.606^{***}	$-28,217$
	(4.48)	(1.51)		(-1.73)	(-3.45)	
Investment costs (in 10,000 Euro)	-0.162^{***}	–	–	-0.099^{***}	–	–
	(-11.15)			(-3.42)		
Investment cost subsidy (in 10,000 Euro)	0.109^{***}	-0.114^{***}	$6,702$	0.123^{***}	0.146^{***}	$12,396$
	(5.11)	(-4.29)		(3.59)	(4.71)	
Heating and hot water costs 2022 (in 1,000 Euro)	-0.479^{***}	-1.557^{***}	$-2,959$	–	–	–
	(-2.92)	(-7.91)				
Net cold rent 2022 (in 1,000 Euro)	–	–	–	-0.110	-2.476^{***}	–
				(-0.29)	(-4.56)	
Annual CO_2 emissions (in tons)	-0.058^{**}	0.440^{***}	$-3,552$	-0.157^{***}	0.493^{***}	$-15,781$
	(-1.97)	(8.31)		(-3.69)	(7.73)	
No energy retrofit	-0.201	2.432^{***}	–	-0.752^{***}	2.401^{***}	$-75,641$
	(-1.14)	(20.71)		(-3.15)	(15.74)	

Table B.4: Estimation results for preferences and WTP for energy retrofits of the interaction model, full model results - continued

	Homeowners			Landlords		
	Mean of the parameter	Std. dev. of the parameter	Mean WTP	Mean of the parameter	Std. dev. of the parameter	Mean WTP
Investment cost subsidy						
x low income	−0.038	–	–	−0.020	–	–
	(−1.38)	–		(−0.41)	–	
x loan or mortgage payments	0.011	–	–	0.015	–	–
	(0.53)	–		(0.58)	–	
x poor capital access	−0.034	–	–	−0.004	–	–
	(−0.93)	–		(−0.06)	–	
x high financial burden	0.038*	–	2,356	0.006	–	–
	(1.84)	–		(0.15)	–	
x high debt aversion	0.008	–	–	0.021	–	–
	(0.39)	–		(0.77)	–	
No energy retrofit						
x low income	0.515**	–	31,782	−0.123	–	–
	(2.39)	–		(−0.38)	–	
x loan or mortgage payments	−0.070	–	–	0.051	–	–
	(−0.42)	–		(0.22)	–	
x poor capital access	0.641**	–	39,565	0.235	–	–
	(2.31)	–		(0.52)	–	
x high financial burden	0.082	–	–	−0.103	–	–
	(0.48)	–		(−0.37)	–	
x high debt aversion	0.683***	–	42,190	0.631***	–	63,481
	(4.21)	–		(2.71)	–	
Number of respondents		1,752			859	
Number of observations		10,512			5,154	

Note: For the SML estimations, the user-written command 'mixlogit' (Hole, 2007b) in Stata and 1000 Haltons draws were used. Negative estimated standard deviations for the random parameters result from the SML estimation algorithm and can be interpreted as being positive (Hole, 2007b). Robust z-statistics in parentheses. * (**, ***) means that the corresponding estimated parameter is different from zero at the 10 % (5 %, 1 %) significance level, respectively.