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Michał Nadolny

https://orcid.org/0000-0001-7870-7485

Department of Process Management
Faculty of Management
Wroclaw University of Economics
and Business, Wroclaw, Poland
michal.nadolny@ue.wroc.pl

Ewa Walaszczyk

https://orcid.org/0000-0002-9119-2727

Department of Process Management
Faculty of Management
Wroclaw University of Economics
and Business, Wroclaw, Poland
ewa.walaszczyk@ue.wroc.pl

Sebastian Walerysiak

Department of Process Management
Faculty of Management
Wroclaw University of Economics
and Business, Wroclaw, Poland
sebastian.walerysiak@ue.wroc.pl

Comparative analysis of decision-making factors of hybrid and emission-free heat source users in single-family houses

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Abstract

Aim/purpose – Energy is traditionally produced using fossil fuels as raw materials, which impacts the environment negatively. Due to the scarcity of fossil fuel supplies, rising prices of energy carriers, and global trends, consumers are turning to renewable energy sources (RES) for home heating. The aim of this study was to determine whether the choice of house heating system using different sources than fossil fuels is driven by any additional components of single-family house users' purchasing decisions besides cost. Based on research results, the prospects for further transformation of thermal energy in single-family housing in Poland towards RES were determined.

Design/methodology/approach – The research on the inhabitants of single-family houses was conducted in December 2022 in Poland. The research method used was a survey using the CATI and CAWI techniques. 600 respondents filled out the questionnaire. The results were statistically analyzed. A non-parametric Kruskal-Wallis test (non--parametric ANOVA) and a post-hoc test were used. The distributions' normality and

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the variances' homogeneity were measured using Kolmogorov–Smirnov and Brownian––Forsythe tests. Calculations were performed using Statistica software.
Findings – The choice of heating energy source in single-family houses, taking CO_2 emissions into account, is not dictated by income level. Instead, it is determined by the number of people in the household. More numerous households opt for a zero-emission heat source. Households using emission-based heating energy sources are significantly more driven by the cost of using heating appliances; their purchase price, reliability, and product quality are more important than those using zero-emission methods. The partial use of renewable energy source solutions promotes further investment in emission-free heat sources.
Research implications/limitations – The analysis illustrates the state of thermal transformation in single-family houses during the energy transition process at the national level. A limitation of the research is that it samples only one EU country struggling with too high CO_2 emissions compared to other countries.
Originality/value/contribution – A unique approach used in this study is to address the variation in incentives for renewable energy purchasing decisions, considering CO_2 emissions. This aspect, although noticeable to some extent, is not directly taken into account by users who do not have the tools to assess their CO_2 emissions. However, the proposed research approach showed that the CO_2 emission level of a heating system is a factor differentiating some aspects of the decision-making process of system users. In particular, it showed what elements of the decision are essential in households that have not yet taken any action towards energy transformation.

Keywords: energy, decision-making process, heat source, hybrid heat sources, emission-free heat sources, consumers' characteristics.
JEL Classification: Q56, G51, O13.

1. Introduction

Energy production is traditionally carried out using fossil fuels as raw materials (Stec et al., 2023). Such production has an enormous negative impact on the environment, mainly due to CO_2 emissions, which have increased in the last years (Chhugani et al., 2023). One of the United Nations' sustainable development goals concerns climate issues and indicates that entire economies should move towards climate-resilient development and try to achieve net-zero emissions (United Nations, n.d.) Also, the uncertain situation in some regions of the world may cause shortages in fossil fuel supplies or unpredictable price increases.

A significant part of energy production worldwide, about one-third, is consumed in buildings (Kou et al., 2023). Energy is an essential resource nowadays in every person's life. It enables heating, lightning, powering home appliances, mobility, and communication. Most energy is consumed solely for space heating and domestic hot water (Gaucher-Loksts et al., 2022; Szymańska et al., 2023). The above reasons make energy consumers turn to renewable energy sources (RES), especially for house heating.

The thermal energy market in Poland is still based on coal combustion (Kuźmiński et al., 2023; Stec et al., 2023). The country is under ecological pressure from the European Union and global regulations and is undergoing an energy transformation. However, it is quite a large country, so implementing such changes is difficult. In Poland, there are subsidies for the purchase of energy, and at the same time, many effective support programs encourage the use of RES in single-family houses (Kuźmiński et al., 2023; Stec & Szymańska, 2022; Szymańska et al., 2022, 2023). Poland's example and research results on factors influencing decisions regarding the choice of energy sources may be an important test case for other countries wishing to implement energy transformation.

The essential factors shaping the demand for heat energy in single-family houses are the inhabitants' income level and the number of people in the household. Therefore, the economic situation and the number of inhabitants may be the reasons for choosing RES (Becker et al., 2018; Kotsila & Polychronidou, 2021; Szymańska et al., 2023; Zeng et al., 2021). The literature shows that energy consumers are guided by specific reasons when choosing energy sources. These are environmental considerations of the equipment, financial aspects of purchase, operation and maintenance, modernity, and even the prestige of attitudes and purchasing choices. Using RES allows for meeting these needs more economically and, at the same time, in the spirit of pro-environmental activities. Such reasons lead to the segmentation of the energy market (Barjak et al., 2022). However, Poland is one of the least developed countries in terms of the use of emission-free energy sources in households (Nowak et al., 2016). Therefore, the implementation of the ecological goals to which Poland is obliged[*] requires a diagnosis of the mechanisms for making purchasing decisions in the single-family house sector.

Because the choice of energy source is influenced primarily by individual demand, the research in this article will be dedicated to identifying the critical decision-making factors of consumers in Poland. Poland seems to be a test field for other countries in Europe. It is relatively large, struggles with various social problems, and at the same time is undergoing an energy transformation because its energy production is based mainly on coal (Kuźmiński et al., 2023; Stec et al., 2023; Stec & Szymańska, 2022; Szymańska et al., 2022, 2023). The research will fill the cognitive gap and help determine whether a user of thermal energy in a single-family house chooses RES or is reluctant to use this heating technology. It will also help diagnose critical aspects of renewable energy users' decisions.

[*] https://www.europarl.europa.eu/factsheets/en/sheet/70/renewable-energy

The authors posted a hypothesis that the choice of home heating method in the context of CO_2 emissions is a derivative of the diversity of selected components of purchasing decisions of single-family house inhabitants and affects their investment plans. The article attempts to diagnose the energy transformation process in a country based on heating systems using solid fuels. An insight into the process initiated ten years ago shows that the current state could be better. Still, some conclusions on consumer behavior and how CO_2 emissions depend on user attitudes and preferences can already be drawn.

This study aimed to determine whether the choice of house heating system using different sources than fossil fuels is driven by any additional cost components of single-family house users' purchasing decisions besides cost. It was verified whether the level of household income per capita and the number of house inhabitants were critical distinguishing features of consumer groups. Moreover, the research was planned to check whether the choice of heating method was motivated by expectations toward heating systems, including expectations about the ecological nature of heat sources. Based on research results, the prospects for further transformation of thermal energy in single-family housing toward RES in Poland were determined.

The structure of the paper is as follows: The next section (Section 2) is dedicated to presenting the literature review, Section 3 describes the research methods, including the research design, research technique, collecting data, and statistical methods of data analysis, and Section 4 presents and discusses the research results. The conclusion (Section 5) ends the paper and proposes future research directions.

2. Literature review

Human activity is one of the significant factors that influence climate change. Rapid population growth, land cover, industrial development, and economic growth cause an increase in energy consumption and utilization of natural resources. It results in global warming and environmental pollution, affecting weather factors and long-term human living conditions (Hidalgo García & Rezapouraghdam, 2023; Yu et al., 2023). The widespread use of fossil fuels is one of the main reasons for these unwanted changes (Kathiravel et al., 2024; Zhang et al., 2023). Many countries have taken steps to reduce greenhouse gas emissions and promote low-carbon solutions. This includes improving energy efficiency, optimizing energy structure, and transitioning to close to zero emissions

as much as possible, with a growing focus on the building sector as responsible for a significant part of energy consumption (Kathiravel et al., 2024; Krikser et al., 2024; Stec & Szymańska, 2022; Zhang et al., 2023; Zhuang et al., 2023).

Studies on heat sources in residential buildings have been conducted in various countries. Kathiravel et al. (2024) investigated the environmental and economic aspects of 36 scenarios, considering three popular heating, ventilation, and air-conditioning systems, i.e., systems powered by electricity, natural gas, and solar sources, with six weather conditions in Canada. The results identified consistent environmental impacts across scenarios. Ground source heat pumps had lower emissions despite higher costs and were preferred when considering environmental and economic factors. However, the air source heat pump was optimal in mild climates. Photovoltaic panels enhanced the feasibility of the systems across various options. Zhuang et al. (2023) explored the feasibility and potential benefits of incorporating air-source heat pumps into existing heating systems to meet heating demands in the United Kingdom. The results indicated that the best hybrid heating system alternative reduces carbon emissions by 88% and total costs by 54%. Air-source heat pumps can meet most of the heating demand during high-demand seasons. Other authors aimed to examine the experiences and expectations of officers responsible for heating technology in municipal authorities across Germany regarding low-carbon heating systems (Krikser et al., 2024). The findings showed that officers in larger cities have more positive expectations of low-carbon heating technologies than those in smaller and medium-sized ones and have more experience with these technologies. These attitudes and experiences influence the desirability and expected feasibility of expanding district heating. The exchange of experiences and expectations between larger and smaller cities could facilitate the transition to low-carbon heating.

Research on the heating sector in Poland (Stec et al., 2023), the second-largest district heating market in the European Union, shows that heat production depends mainly on coal, which is why it will require transformation in the coming years. Thermal energy companies modernizing their installations more often use low-emission technologies than zero-emission ones, as they intend to participate in decarbonizing the heating system and reducing greenhouse gas emissions – another research concerned energy innovations from local governments in Poland (Stec & Szymańska, 2022). The activities of 30 communes were researched in energy-related construction, transport innovations, and social campaigns. The results show that 50% of the surveyed local governments are inno-

vative, and the remaining are moderately innovative; no commune was non--innovative. Smaller municipalities, mainly rural ones, concentrate more on implementing solutions that consider climate and energy policy adoption.

Szymańska et al. (2022, 2023) researched energy transformation in Polish households in the face of the energy crisis. Their results indicate that fossil fuels still dominate in energy production in households in Poland, and the share of RES in energy consumption in 2020 was 16.1%, with the domination of photovoltaic installations at 52%. In residential buildings, household energy demand depends on the year a building was commissioned. Newer buildings may install smaller heat energy systems. Many households are undertaking activities to modernize their buildings thermally. Respondents indicated that an increase in energy prices and interruptions in energy supplies would encourage them to change their heating systems into installations for RES. Still, the main barrier to the development is financial. Allowances and subsidies should be introduced, and social awareness should be increased. Other recent research conducted in Poland is also concerned with technical aspects of thermo modernization (Kaya et al., 2021; Szulgowska-Zgrzywa et al., 2022).

The inevitable direction of climate change in individual energy consumption, especially heating, is using RES instead of fossil fuels. The European Union has established an environmental goal in this area and included it in the Directive EU/2023/2413 called RED (Renewable Energy Directive) III[**]. It sets the new target of at least 42,5% share of renewable resources in energy production in 2030, up from the current target of 32%. This means almost doubling the current share of renewable energy. Europe will voluntarily strive to achieve a share of 45% in the energy mix by 2030.

Among European Union member countries, Sweden leads with more than half of renewable energy in energy consumption (62.6%) in 2021 (TL, 2023). The following places took Finland (43.1%) and Latvia (42.1%). Outside the Union, there are countries with a much higher share of RES than the EU leader, Iceland and Norway, with 85% and 74 % of energy from renewable sources. In total, 15 of the 27 EU members are below the EU average in 2021 (Belgium, Bulgaria, Czech Republic, Germany, Ireland, Spain, France, Italy, Cyprus, Luxembourg, Hungary, Malta, the Netherlands, Poland, and Slovakia). The lowest percentage of renewable energy was recorded in Luxembourg (11.7%), Malta (12.2%), and the Netherlands (12.3%). Poland was sixth from the bottom, with the share of RES in energy consumption at 15.6% (TL, 2023).

[**] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413

To overcome the problem of using fossil fuels to heat houses, Poland is introducing anti-smog laws and requiring the replacement of heating systems in single-family homes in the next few years. To encourage residents, much financial support is offered through grants, low-interest loans, and tax breaks (Stec et al., 2023; Stec & Szymańska, 2022; Szymańska et al., 2022, 2023).

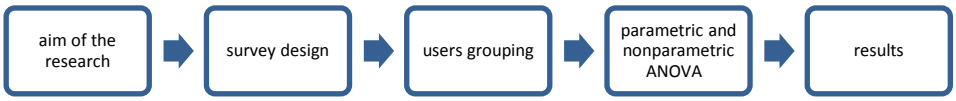
Among the criteria that would convince energy consumers in different countries to change their heating source to renewable sources are comfort (thermal comfort, air quality, ease to use), energy efficiency, environmental impact (CO_2 emission, resource availability), financial issues (investment costs, payback period, energy bills) and social acceptance (Balezentis et al., 2021; Mohammad Husain et al., 2024; Wahi et al., 2023; Wen et al., 2023).

3. Research methodology

3.1. Research design

The research process had a few stages. The first one was to identify the research problem, the hypothesis, and the aim of the research. It was necessary to determine the research gap and to design and conduct the research correctly. These elements are presented in the Introduction of this article. The second stage was to design the survey. The questionnaire was created by the authors based on the hypothesis that system users can evaluate the heating systems used in terms of their efficiency, costs, and environmental aspects. Fundamental aspects of buyers' behavior in purchasing decisions were used (price, advice, quality). The form of the survey and measurement scales were dictated by the measurement methodology for factor analysis and structural equation modeling (this aspect will be the subject of further research). A pilot study was conducted, which showed that a 5-point scale is sufficient for measurement. The survey questionnaire is attached in the Appendix (Table 10). In the next stage, respondent grouping was realized after the answers were collected. This stage aimed to divide the respondents into three groups, considering the heating systems installed in their houses. It was necessary for further statistical analysis of results, which was the fourth stage of the process. Here the main factors influencing the decision-making process were identified. The final stage was receiving and explaining the results. The scheme of the research is presented in Figure 1.

Figure 1. The scheme of the analysis



Source: Authors' own study.

3.2. Research technique

The research used CATI (Computer-Assisted Telephone Interview) and CAWI (Computer-Assisted Web Interview) techniques to collect information quantitatively. The respondents were asked to complete a survey either by telephone or online. The questionnaire consisted of 79 questions, 31 of which aimed to identify respondents' characteristics and data regarding the inhabited property and household. The remaining 48 research questions were related to the inclinations and assessments of users of single-family houses.

The survey questions were divided into three main groups:

1) critical elements of general purchasing decisions, without referring to the aspect of using RES,
2) relating directly to users' expectations towards heating systems,
3) assessment of the currently used heating system and investment plans in heating systems.

3.3. Collecting data

The survey took place in Poland in December 2022, coinciding with the start of the heating season. The respondents were invited to the study based on Poland's database of single-family house inhabitants. The respondents selected for the study represented only households living in single-family, terraced, or semi-detached houses. These residents constituted the sampling group (by address). The selection of respondents for the study was random throughout the country.

Completing the survey was preceded by three questions verifying the fulfillment of the criteria for the research group:

1. Does the respondent live in a single-family house?
2. Did the respondent personally decide on a heating device?
3. What is the heating source?

The answers to the two first questions must have been a "yes." In response to the third question, only houses equipped with one of four devices were included: a heat pump, photovoltaic panels, a condensing gas furnace, or an electric flow furnace. Due to research purposes, houses entirely heated with solid fuels or connected to heating networks were excluded from the sample. If the answers to the opening questions were different than indicated above, a person did not participate in the study.

The database of single-family house residents in Poland contains over two million records. The required size of a representative sample for assessing the fraction size was 384, assuming a maximum error of 5%. The authors decided to collect more answers. Finally, the questionnaire was filled out by 600 respondents, who met the criteria from the initial verifying questions. The study was conducted once 600 fully completed questionnaires were obtained. The respondents represent the population of households in single-family houses using heating other than solid fuels in Poland. In this way, the survey represents this specific group of respondents throughout the country. The presented research, therefore, meets the condition of representativeness and can be generalized to the entire population of houses in which one of the four devices mentioned above is used.

3.4. Respondents' characteristics

As mentioned above, the questionnaire was filled out by 600 respondents. The majority of them were women (62.8%). Nearly one-third were aged between 31 and 40 (29.5%), and one-fourth were between 41 and 50 (25.3%). The third largest group were people between 51 and 60 (22.2%). The respondents were well-educated; the most prominent group were people with a master's degree or equivalent (35.5%) and a bachelor's degree or equivalent (12.5%). One-fifth of respondents lived in the village (20.2%), the rest of them in cities, with most in large cities, 200-500 thousand inhabitants (20.5%) or larger (19.7%). The sample is representative of the population of Poland, so the respondents live in all 16 voivodeships. A typical household consists of four (30.0%), three (25.3%) or two people (21.0%). Most respondents' net monthly income per capita is at least as high as the national average income (100% or more) – 76.1%. The age of the house heating installation is, in most cases, five years old or less (78,6%). Most respondents changed their heating system in the last ten years (96%). The selected characteristics of respondents are presented in Table 1.

Table 1. Selected characteristics of the research sample (n = 600)

Characteristics	Category	Percentage
Voivodeship (n = 600)	Lower Silesian	7.8%
	Kuyavian-Pomeranian	5.0%
	Lublin	5.5%
	Lubusz	2.5%
	Łódź	6.7%
	Lesser Poland	8.8%
	Masovian	14.3%
	Opole	2.2%
	Subcarpathian	5.8%
	Podlaskie	3.3%
	Pomeranian	6.0%
	Silesian	11.8%
	Holy Cross	3.0%
	Warmian-Masurian	2.8%
	Greater Poland	9.7%
	West Pomeranian	4.7%
Number of inhabitants in a household (n = 600)	1	3.8%
	2	21.0%
	3	25.3%
	4	30.0%
	5	14.0%
	6	3.2%
	7+	2.7%
Total net monthly income per capita in terms of national averages (GUS 2023) (n = 429)	less than 20%	15.9%
	20%-40%	4.2%
	40%-60%	3.0%
	60%-80%	8.6%
	80%-100%	10.7%
	100%-120%	16.6%
	120%-140%	15.9%
	140%-160%	11.2%
	160%-180%	12.6%
	180%-200%	11.9%
	more than 200%	7.9%

Source: Authors' own research.

3.5. Statistical analysis of collected data

The survey of heating system users' decision-making factors was designed to measure the relevance of specific decision components. Achieving the study's goal required determining the method of measuring individual aspects of the diagnosis of respondents' decisions. Different scales were used to answer vari-

ous questions. The list of possible answers and the types of variables obtained is presented in Table 10 in the Appendix.

A ratio scale was used concerning income, and an interval scale was used to determine the household size. For these types of variables, it is required to assess the normality of the distributions and the homogeneity of the variances. It was done with the Kolmogorov-Smirnov test for normality and the Brownian––Forsythe test for homogeneity. As the distributions of these two variables cannot be considered normal, non-parametric ANOVA tests were necessary.

Questions related to the inclinations and assessments of users of single-family houses were based on a 5-point ordinal Likert scale with a neutral point. Using a unified scale for all questions on decision factors made it possible to measure the variation in ratings across groups of respondents. Differences were measured using a non-parametric Kruskal–Wallis test (non-parametric ANOVA) and a post-hoc test dedicated to this type of analysis. This is the required method for this type of variable. All calculations were performed using Statistica software.

4. Results

From the point of view of this study, the declarations of respondents relating to the heating method in the context of CO_2 emissions were crucial. Based on the information obtained about the heating devices used by the respondents, three groups of users were identified expertly (Table 2):

1 0%-emitters: people who choose only emission-free heating based on their own RES thermal energy sources: heat pump, photovoltaics with a storage electric furnace, solar heating panels.
2 Partial emitters: people who partially use RES, but also use emission heating: oil, gas, or solid fuels, excluding coal. The emission heating method, however, is not primary heating but auxiliary or emergency heating.
3 100%-emitters: people who heat their houses only with gas and do not have any renewable energy installations.

Table 2. Groups of heating system users (n = 600)

Group	Type of home heating	Percentage
1	0%-emitter (only RES)	11.1%
2	partial emitter (RES and gas)	12.5%
3	100%-emitter (no RES)	76.4%

Source: Authors' own research.

Considering that respondents in some regions of the country may be more willing to replace their heating system with a more pro-ecological one due to climate conditions, the analysis of groups of heating system users in division into voivodeships is presented in Table 3. The data were sorted in descending order by 0%-emitters share in the voivodeship. Lubusz has the highest proportion of 0%-emitters at 20%. It is a region in the center-western Poland. The following three places with a 16-17% share took voivodeships from the central part of the country. Pomeranian, which had the last place with 5.5% of 0%-emitters in the voivodeship, is located in the north of Poland.

Table 3. Groups of heating systems users by voivodeship (n = 600)

Voivodeship	0%-emitter	partial emitter	100%-emitter	0%-emitters share in the voivodeship (share in the sample inside the voivodeship)
	Share in total sample (n = 600)			
Lubusz	0.50%	0.00%	2.00%	20.00%
Warmian-Masurian	0.50%	0.50%	1.83%	17.65%
Łódź	1.17%	0.67%	4.83%	17.50%
Holy Cross	0.50%	0.67%	1.83%	16.67%
Podlaskie	0.50%	0.83%	2.00%	15.00%
Greater Poland	1.33%	0.67%	7.67%	13.79%
Kuyavian-Pomeranian	0.67%	0.33%	4.00%	13.33%
Silesian	1.50%	2.17%	8.17%	12.68%
Lublin	0.67%	0.33%	4.50%	12.12%
West Pomeranian	0.50%	0.50%	3.67%	10.71%
Lesser Poland	0.83%	1.00%	7.00%	9.43%
Subcarpathian	0.50%	0.33%	5.00%	8.57%
Opole	0.17%	0.33%	1.67%	7.69%
Masovian	1.00%	2.00%	11.33%	6.98%
Lower Silesian	0.50%	1.17%	6.17%	6.38%
Pomeranian	0.33%	1.00%	4.67%	5.56%

Source: Authors' own research.

The distribution of the type of heating device (% in total sample) used by respondents from each voivodeship is presented in Table 4. Gas is the most popular heating source among those allowed in the research sample. Most households with gas heating systems are in Masovian, which accounts for over 10% of the total sample, then in Silesian and Greater Poland, over 7% each, and Lesser Poland and Lower Silesian with 6%. Other heating systems are much less prevalent.

Table 4. Type of heating device (dominant) (n = 600)

Voivodeship	Gas	Heat pump	Hybrid	Electric
Lower Silesian	6.00%	1.00%	0.00%	1.50%
Kuyavian-Pomeranian	3.33%	0.67%	0.50%	1.50%
Lublin	4.17%	1.00%	0.17%	1.83%
Lubusz	1.67%	0.33%	0.17%	0.67%
Łódź	5.00%	1.00%	0.67%	1.17%
Lesser Poland	6.83%	1.33%	0.83%	2.00%
Masovian	10.83%	1.83%	0.67%	2.67%
Opole	1.67%	0.50%	0.00%	0.17%
Subcarpathian	4.83%	0.33%	0.50%	0.83%
Podlaskie	2.17%	1.00%	0.50%	0.83%
Pomeranian	4.00%	0.67%	0.33%	2.33%
Silesian	7.83%	2.50%	0.50%	3.33%
Holy Cross	1.50%	1.00%	0.17%	1.17%
Warmian-Masurian	1.33%	0.33%	0.17%	1.33%
Greater Poland	7.50%	1.33%	0.67%	1.50%
West Pomeranian	3.50%	0.67%	0.17%	1.50%

Source: Authors' own research.

The above analysis is a sample analysis. It does not affect the results described in the paper. For additional research, a deeper analysis of the answers given by respondents by voivodeships in the context of factors influencing purchasing decisions is planned.

In the first step, the research's aim and hypothesis were analyzed using two measurable factors describing household characteristics: average income to average GDP in Poland and household size. Both variables are expressed in ratio scales; therefore, testing the normality of distributions and the equality of group variances is necessary. Table 5 shows that the distributions cannot be treated as usual; hence, the analysis of differences between the segments of single-family house users specified above was examined using the Kruskal–Wallis non-parametric ANOVA.

The analysis results show that the choice of heating method is separate from total net monthly income per capita. All three groups should be considered relatively similar. However, the situation is different concerning the number of household inhabitants. A clear difference can be observed concerning the groups of 100%-emitters and 0%-emitters. Households using a comprehensive RES system are larger (half of the households of this type are families of 3-4 people) than 100%-emitters (half of the households of this type are families of 2-3 people). The distribution of numbers in individual groups is presented in Figure 2.

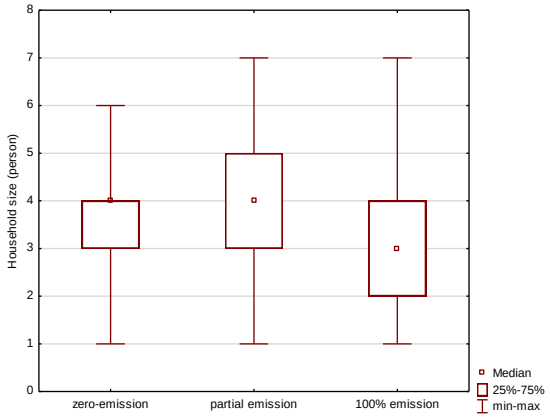
Table 5. Evaluation of properties of variable distributions and results of non-parametric tests

Variable	Kolmogorov–Smirnov test for normality	Brown–Forsythe test of the equality of group variances	Kruskal–Wallis (K–W) test of ranks	Multiple comparison test (only significant results)	Decision
Total net monthly income per capita*	$p < 0,01$	$p = 0,297$	$p = 0,951$	–	Income is not the factor that differentiates the three user groups identified
Household size*	$p < 0,01$	$p = 0,925$	$p = 0,004$**	$p = 0,006$**	Household size is the factor that differentiates the identified three user groups. 100%-emitters differ significantly from partial and 0%-emitters

* Distribution is not normal, variance differences are statistically insignificant, and the exact shape of the distribution is observed in the groups.
** Median differences are statistically significant.

Source: Authors' own research.

Figure 2. The distribution of numbers in individual groups of household size



Source: Authors' own research.

In the surveyed sample, properties are most often inhabited by three (29%) or four people (32%). People living alone constitute less than 3% of the sample. Properties occupied by more than five people comprise 23% of the surveyed sample (Table 1). As the study results show, the number of household members is an essential determinant of investment decisions in renewable energy. The relationship consists of a strong correlation between household size and electricity and heat con-

sumption. The analysis of the results obtained based on the respondents' general purchasing propensities (Table 6) and expectations regarding the heating systems used (Table 7) provided an exciting and entirely unexpected result.

Table 6. Results of non-parametric tests for determinants of purchasing decisions

What guides your decisions relating to the equipment you purchase?*	p-value: Kruskal–Wallis test of ranks	p-value multiple comparison tests (only significant results)	Decision
low operation costs	0.001	0.005	The factor importance is lower for 0%-emitters than for 100%-emitters
price for goods or services	0.002	0.008	
reliability	0.002	0.013	
the quality of the goods purchased or services provided	0.046	0.009	
possibility of remote control (e.g., mobile application)	0.054	–	No differences
warranty period	0.090	–	
after-sales service related to technical support	0.097	–	
easy operation	0.125	–	
recommendations on Internet forums	0.226	–	
recommendations from an advisor in the store	0.335	–	
the goods or service is environmentally friendly	0.352	–	
opinions of loved ones	0.391	–	
appropriate appearance or design	0.455	–	
prestige of the brand or manufacturer	0.458	–	
warranty service	0.623	–	
the goods have certificates confirming their environmental performance	0.803	–	
possibility of configuration and personalization	0.981	–	

* Independent of observations in the sample, the exact shape of distribution in groups is observed.

Source: Authors' own research.

The analysis showed four decision-making categories differentiating heating system users by specific emission levels. People who heat their houses using only emission devices gave higher importance ratings in these four decision-making components. Therefore, in their everyday decisions relating to purchased equipment and goods, low operating costs, price for goods or services, reliability, and the quality of the goods purchased or services provided are significantly more critical for 100%-emitters than for people choosing completely emission-free heating devices (Table 6).

The respondents were asked to evaluate the selected properties of the heating system if they decided to replace it today. The research results show that only two elements differentiate the groups of users. One is the ability to control the heating device; 100%-emitters rate this aspect higher than partial emitters. The second aspect is low operating cost, which is more critical to partial emitters. In other aspects of the assessment of expectations towards heating systems, no relationship with decisions about the choice of heating devices can be established (Table 7).

Table 7. Results of non-parametric tests for expectations from the heating device

What are your expectations from the heating device you currently use?	p-value: Kruskal–Wallis test of ranks	p-value: multiple comparison test (only for K-W significant results)	Decision
the ability to control with a mobile application or remote control	0.004*	0.028**	The factor importance is lower for partial emitters than for 100%-emitters
low operating costs (including maintenance and upkeep) of the heating system	0.002*	0.036**	The factor importance is higher for partial emitters than for 100%-emitters
the energy efficiency of the heating device	0.029*	p > 0.126	No differences
heating equipment should generate low heating costs	0.004*	p > 0.129	
brand or manufacturer of the device	0.093	–	
technical characteristics of the heating device	0.446	–	
heating devices should be environmentally friendly	0.676	–	
low price of the device	0.747	–	

* Test K–W (Kruskal–Wallis test) statistically significant.
** Difference in groups statistically significant.

Source: Authors' own research.

Table 8 summarizes the results of comparing essential aspects of the assessment made by respondents. The median and average scores were provided as the basis for the analysis of the Kruskal–Wallis test.

Table 8. Summary of basic statistics for variables significantly differentiated by the house heating method (n = 600)

	Mean		Median*	
	0%-emitters	100%-emitters	0%-emitters	100%-emitters
Total net monthly income per capita	5.75	5.71	5.5	5.5
Household size	3.58	3.41	4.0	3.0
	0%-emitters	100%-emitters	0%-emitters	100%-emitters
Low operating cost	1.04	1.49	1.0	2.0
Price for goods or services	0.89	1.36	1.0	2.0
Reliability	1.19	1.61	2 (244**)	2 (308**)
The quality of the goods purchased or services provided	0.98	1.39	1.0	2.0
	partial emitters	100%-emitters	partial emitters	100%-emitters
The ability to control with a mobile application or remote	1.29	1.59	1.0	2.0
Low operating costs (including maintenance and upkeep)	0.72	0.34	1.0	0.0

* Median difference statistically significant.
** Due to the Likert scale, medians across samples are equal; the value represents the sum of the ranks for each sample in the K–W test.

Source: Authors' own research.

Investment declarations indicate a very high interest in installing photovoltaic panels (Table 9). It applies to all market groups. According to declarations, the heat pump is most popular in the partial emitters group. This clearly illustrates the direction of the energy transformation. Representatives of all groups strive for self-sufficiency and reduction of CO_2 emissions. Even the current group of 100%-emitters is entering the transformation path. First, this will apply to photovoltaic panels, which, in addition to heating, provide additional benefits, i.e., electricity billing on a commercial basis. This aspect is the most attractive for 100%-emitters. Heat pump installation is declared by 18% of respondents; it is also a necessary declaration. This result clearly indicates that the transformation in the 100%-emitters group will continue. These types of users will enter the partial emission segment.

Table 9. Percentage of respondents planning to purchase an appliance in the next two years by market group (n = 600)

Appliance	0%-emitters	Partial emitters	100%-emitters
Heat pump	25%	45%	18%
Photovoltaic panel	46%	49%	44%
Other RES systems (hybrid, energy storage)	19%	35%	9%

Source: Authors' own research.

5. Discussion

Choosing a heating source for a single-family house is a critical issue today in the face of constantly growing environmental pollution. In this study, the authors decided to check what reasons respondents took into account when deciding to change the heating source to a more ecological one than those using solid fuels. As described in Section 0, one of the opening questions for completing the survey was about the respondent's house heating source. Only houses equipped with a heat pump, photovoltaic panels, a condensing gas furnace, or an electric flow furnace were included in the research group. Houses entirely heated with solid fuels or connected to heating networks were excluded from the sample.

The reason for selecting respondents using the above-mentioned home heating systems for the research group was that in Poland, many social programs financially support the replacement of solid fuel furnaces with ones that emit less CO_2: gas or renewable energy (Stec et al., 2023; Stec & Szymańska, 2022). The level of co-financing reaches up to 75% of the investment costs. People who constantly use solid fuels as their primary heat source are not guided by either ecological considerations or the financial aspect of the investment. They were unwilling to take any action to reduce or eliminate emissions, regardless of the emission standards of using solid fuels. These are people who still need to undertake activities aimed at energy transformation. Therefore, they did not constitute a group of pro-ecological users and were excluded from the sample.

Note that the study's goal was to identify the decision-making mechanisms of people whose choice of house heating method is pro-ecological to a certain extent. Due to solid particles and CO_2 emission in coal furnaces, this heating method is not classified as pro-ecological. However, the study included people who heat their properties exclusively with gas. As the respondents' characteristics analysis shows (Section 0), 96% of respondents changed their heating method in less than the last ten years. Therefore, people who heat houses with gas should also be considered individuals who have, to some extent, reduced the emission of harmful substances into the atmosphere by giving up less ecological forms of heating.

Based on the answers to the survey opening questions, the respondents were divided into three groups, depending on their declarations relating to the heating method in the context of CO_2 emissions (Table 2). The groups were: 0%-emitters, partial-emitters, and 100%-emitters. The division of respondents into three groups depending on the emissivity of the house heat source made it possible to analyze the respondents' answers in this context. Such segmentation of the respondents is a common practice (Barjak et al., 2022).

The analysis of the sample in the context of the voivodeship (Table 3) showed that the change to a 0%-emission heat source may partly correspond with the climate conditions that encourage residents to change their heating systems to RES, as central and eastern parts of Poland are the sunniest and the north the least. In other studies (Szymańska et al., 2022), climate conditions were not regarded as necessary when changing the house heating system. Gas is the most common heating source (Table 4). Other heating systems are much less prevalent. Such results are consistent with the results of other authors when considering heat sources other than solid fuels (Szymańska et al., 2023).

The research presented in the paper aimed to determine whether the choice of a house heating system using different sources than fossil fuels is driven by any additional components of single-family house users' purchasing decisions besides cost. Two measurable factors describing the household characteristics were analyzed: the average income to the average GDP in Poland and the household size. The research aimed to check if these two factors were critical distinguishing features of consumer groups. The analysis of the research results did not provide grounds to conclude that the level of net income per capita was related to the choice of heating device in any way. Perhaps this was because of the numerous subsidies for households that can be used to change the heating system. They somehow eliminate the financial factor of the investment (Kuźmiński et al., 2023), but the price of RES installations and prices for energy were the most crucial factors encouraging households to invest in RES (Szymańska et al., 2022).

Instead, there is a clear relationship between household size and the use of RES. Households using RES are more numerous (half of households of this type are families of 3-4 people) than 100%-emitters (half of households are families of 2-3 people). This relationship is logical: the larger the family, the greater the energy demand. This definitely encourages the use of cheaper heating devices, such as RES. The savings during operation can be expected to be more significant, if the household is larger. The result of this relationship is also confirmed in other studies, and the relationship consists of a strong correlation between the size of the household and the consumption of electricity and heat (Becker et al., 2018; Kotsila & Polychronidou, 2021; Zeng et al., 2021). However, it should be emphasized that in our research, income per capita issues had no impact on investment decisions in renewable energy.

The next part of the survey questions concerned factors influencing the decision on the house heating system. The analysis of the answers showed that 100%-emitters pay attention to the following aspects: low operating costs, price for goods or services, reliability, and the quality of the goods purchased or ser-

vices provided. This group gave higher weight to these factors than 0%-emitters. This is an interesting result that requires explanation. The four factors mentioned generally come down to minimizing the costs of purchasing and operating devices. A clear perception of financial aspects and the quality of goods (typically not only heating devices) distinguishes two extreme segments of heating system users. At the same time, it was shown that net income per capita is comparable in the studied groups of users, so it can be assumed that a different approach to spending money is observed in the groups of 100%-emitters and 0%-emitters. Both segments may also be differentiated by their approach to modern technologies, novelties, and evaluation of developing systems, although yet to be established (Barjak et al., 2022). This issue should have been included in the analysis in this paper. Partial emitters do not differ from both extremes. People using mixed systems are a transitional group: in the light of the methodology, they do not differ from either 0% -emitters or 100%-emitters.

This clearly distinct group of 0%-emitters does not differ statistically from the other two groups' expectations of heating devices. It can be assumed that 0%-emitters represent opinions from both other groups. However, the influence of the diversity of partial emitters is noticeable. With regard to 100%-emitters, an essential factor in using the devices is the ability to control them with a mobile application or remote control. This contradicts the result regarding everyday purchasing decisions, where this aspect was not so clearly exposed in this group. Please note that this feature of heating devices also applies (or perhaps primarily) to modern renewable energy systems. It can be hypothesized that 100%-emitters are unaware of the possibilities of renewable energy heating systems. This study cannot determine why this is the case. It is possible that such users are not interested in obtaining information, are characterized by some aversion to new solutions, and are attached to what is known to them. The analysis of this issue is an interesting extension of the presented research. Another inconsistency in the 100%-emitters group is that they assess the costs of operating and maintaining heating systems as unimportant. Nevertheless, this aspect of general purchasing preferences was the most important for this group. This may indicate two potential reasons: the above-mentioned lack of knowledge about the costs of operating RES or the complete acceptance of gas heating costs, to the point that it is utterly indifferent to 100%-emitters. Another reason for further exploration of the issue is the attitude of partial emitters who already use RES and, at the same time, declare that the aspect of operation and maintenance costs is essential to them. It is interesting whether this group is inclined to develop RES and completely eliminate CO_2 emissions.

Other authors indicate that such multicriteria decisions represent complex problems where disparate knowledge areas must be considered simultaneously. Identifying factors influencing the decision-making process provides only a snapshot of preferred alternative. It is essential to consider likely future changes to the value perceptions of decision-makers when making decisions with long lifetimes (Wen et al., 2023).

The conducted study presented the variation in incentives for renewable energy purchasing decisions, taking into account the CO_2 emission level. The proposed research approach showed that the CO_2 emission level of a heating system is a factor differentiating some aspects of the decision-making process of system users. This shows what elements of the decision are essential in households that have not yet taken any action toward energy transformation.

The last part of the survey concerned the respondents' investment plans. Partly using RES solutions promotes further investment in emission-free heat sources. Representatives of all groups of respondents strive for self-sufficiency and reduction of CO_2 emissions. Even the current group of 100%-emitters is entering the transformation path. However, the survey did not consider the most conservative and, at the same time, most problematic group of users of solid fuel furnaces. In Poland, a ban on this type of heating is gradually being introduced. This problematic, omitted segment of heat energy consumers may decide to switch to gas fuel first. This requires the least investment outlays and interferes the least with the existing heating system. Nevertheless, sharp increases in the prices of gas and other energy carriers (including coal) may encourage consumers to enter the partial or even 0%-emitters segment. Such conclusions may also be supported by the results of other research (Balezentis et al., 2021; Szymańska et al., 2022, 2023). The analysis of this problematic sector is an interesting prospect for further research.

The prospects for Poland are favorable. The transformation of household heating sources will occur; partial emitters will enter the renewable energy path and plan to develop the systems used; therefore, they will gradually move to the group of 0%-emitters. Investment declarations indicate a very high interest in installing photovoltaic panels (Table 9). It applies to all groups of respondents, indicating the willingness to energy self-sufficiency and reduction of CO_2 emissions. People who only use gas for heating will also want to use photovoltaic panels first, and then they will be interested in a heat pump. The high price of gas certainly encourages them to do so. Entering the renewable energy path, partial emitters will develop their heating systems and gradually move to the group of 0%-emitters.

The hypothesis posed by the authors that the choice of home heating method in the context of CO_2 emissions is a derivative of the diversity of selected components of purchasing decisions of single-family house inhabitants and affects their investment plans were verified positively. The aim of the research was also achieved. The obtained results showed that the choice of a pro-ecological house heating system is driven by additional, besides cost, components of single--family house users' purchasing decisions, namely by the number of inhabitants in the household. The research also showed that the choice of heating method was motivated by certain expectations towards heating systems. Based on research results, the prospects for further transformation of thermal energy in single-family housing in Poland towards RES were determined.

6. Conclusions

The main conclusions from the research are:

1. The choice of heating energy source in single-family houses, taking CO_2 emissions into account, is not dictated by income level. Instead, it is determined by the number of people in the household. More numerous households opt for a zero-emission heat source.
2. Among factors influencing the decision on the house heating system, households using emission-based heating energy sources are significantly more driven by the cost of heating appliances; their purchase price, reliability, and product quality are more important than those using zero-emission sources.
3. Investment declarations indicate a very high interest in installing photovoltaic panels. It applies to all groups of respondents, indicating the willingness to energy self-sufficiency and reduction of CO_2 emissions.

The presented issues significantly contribute to the research on factors that influence the decision-making process about changing the house heating source to more ecological. It is essential to know how consumers decide, why they choose specific devices, and what criteria they consider when making a decision. It is vital nowadays when we all are fighting increasing environmental pollution, and some countries use social programs to support the replacement of solid fuel furnaces financially. Some countries are leading in using RES, but Poland is not among them. That is why such research is necessary.

The possible implications of the research findings for practitioners may be formulated. The producers of heating devices may use the results of the presented study to direct the offer better, knowing what factors are critical in the decision-making process for certain groups of customers. Additionally, the factors

indicated in the study can be used to shape pro-ecological attitudes through social programs, incentives, subsidies, etc. The activities undertaken on the whole country scale may be addressed better by knowing what the consumer is guided by when deciding to change the house heating system.

Every research has some limitations. The limitation of this study was that it only sampled respondents from one EU country, Poland, which struggles with too high CO_2 emissions compared to other countries. Similar research in other countries would help understand the broader perspective of the decision-making process and compare the factors influencing the decisions on energy sources for house heating between countries.

Future research should focus on characterizing the decision-making factors of two groups of users: those who have not used RES to any extent so far and those who use 100% emission-free heating energy sources. The results discussed in this paper let us assume that these two groups not only perceive certain decision-making aspects differently but also follow different criteria for the perception of RES devices. Therefore, this study needs to be developed to measure RES purchasing factors and detect hidden decision structures using statistical analysis, e.g., EFA and PLS-SEM methods. Another direction of further research is to analyze the decision-making factors in the context of specific characteristics of respondents, e.g., place of living. Different criteria are taken into account by respondents living in regions where RES are not yet cost-effective.

Disclosure statement

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Appendix

The questionnaire used in the research with possible answers and the type of variables received are presented in Table 10.

Table 10. The questionnaire used in research and the type of possible answers

Question	Possible answers	Type of variable
1	*2*	*3*
Sex	man/woman	nominal
Age	number of years	numeric
Education	list of 11 nominal education levels	nominal
Town size	village, towns [in thousands of habitants]: 20-49, 50-99, 100-249, 250-499, more than 500	interval
Voivodeship	list of 16 voivodeships	nominal
Have you replaced a heating appliance in the last 10 years?	yes/no	numerical dichotomous
household size	number of inhabitants	numeric
total net monthly income	number in thousands PLN	numeric
Usable area of the apartment		
<100 m^2	single choice (0-no/1-yes)	numerical dichotomous
101-150 m^2		
151-200 m^2		
201-250 m^2		
>250 m^2		
residence time	the approximate number of years	numeric
Heating source		
Oil	multichoice	numerical dichotomous
Gas		
Heat pump		
Electric		
Hybrid		
ADDITIONAL Coal or wood	single choice (additional, not obligatory)	
Hybrid: Electric+Fotovoltaics		
Hybrid: Gas+Fotovoltaics		
Hybrid: Heat pump+Fotovoltaics		
Hybrid: Gas+Heat pump		
Hybrid: Electric+Heat pump		
Other		text

Table 10 cont.

1	*2*	*3*
Is this important to you in your everyday purchasing decisions?		
Decision making_1. price for goods or services	Likert scale: definitely doesn't matter –2, rather doesn't matter –1, neutral/I don,t know 0, rather important 1, very important 2	ordinal
Decision making_2. the quality of the goods purchased or services provided		
Decision making_3. the goods or service is environmentally friendly		
Decision making_4. the goods have certificates confirming their environmental performance		
Decision making_5. reliability		
Decision making_6. opinions of loved ones		
Decision making_7. recommendation on Internet forums		
Decision making_8. recommendation from an advisor in the store		
Decision making_9. easy operation		
Decision making_10. warranty period		
Decision making_11. warranty service		
Decision making_12. after-sales service related to technical support		
Decision making_13. appropriate appearance or design		
Decision making_14. prestige of the brand or manufacturer		
Decision making_15. possibility of configuration and personalization		
Decision making_16. possibility of remote control (e.g. mobile application)		
Decision making_17. low operating costs		
Do you plan to install one in the next two years?		
Investments plans_1. heat pump	0 –no/1 – yes	numerical dichotomous
Investments plans_2. gas boiler		
Investments plans_3. photovoltaic panels		
Investments plans_4. oil boiler		
Investments plans_5. accumulation stove		
Investments plans_6. convector heater		
Investments plans_7. hybrid device		
Investments plans_8. connection to a district heating network		
Investments plans_9. solid fuel stove (e.g., coal or wood)		

Table 10 cont.

1	*2*	*3*
Based on your knowledge, how would you rate the following heating devices?		
Evaluation of systems_1. oil boiler	Likert scale: negative –2, rarher negatyve –1 neutral/I don't know 0 rather positive 1, positive 2	ordinal
Evaluation of systems_2. gas boiler		
Evaluation of systems_3. heat pump – air water		
Evaluation of systems_4. heat pump – brine water		
Evaluation of systems_5. heat pump – water		
Evaluation of systems_6. hybrid heat pump		
Evaluation of systems_7. accumulation furnace		
Evaluation of systems_8. photovoltaic panels		
Evaluation of systems_9. convector heater		
What would you expect from the heating system in your home?		
Expected char_1. heating devices should be environmentally friendly	Likert scale: definitely not –2, rather not –1, neutral/I don't know 0, rather yes 1, definitely yes 2,	ordinal
Expected char_2. heating equipment should generate low heating costs		
Expected char_3. low operating costs (including maintenance and upkeep) of the heating system		
Expected char_4. brand or manufacturer of the device		
Expected char_5. technical characteristics of the heating device		
Expected char_6. the ability to control with a mobile application or remote control		
Expected char_7. low price of the device		
Expected char_8. the energy efficiency of the heating device		

Source: Authors' own research.