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How to Reduce Low-Stack Emissions? An Assessment of the Willingness of Residents of Single-Family Houses to Replace Fossil Fuel Heating Systems

Abstract

Objective: The objective of this study is to determine whether occupants of single-family houses in Poland, where low-stack emissions have a particularly negative impact on air quality, are willing to replace their current fossil fuel heating systems. To that end, four research hypotheses were formulated: 1. The majority of households using solid fuel boilers are considering switching to another heat source; 2. Their willingness to replace solid fuel boilers is affected by several statistically significant factors; 3. The main impediment to replacing the heat source is its cost; and 4. The anticipated amount of subsidy is critical in deciding whether or not to purchase a new heat source.

Research Design & Methods: This research was considered in the context of data from a CATI survey conducted in July and August 2021 among a representative sample of occupants of single-family houses in Poland. A total of 1007 responses were collected, of which 432 were considered in the subsequent analysis. A literature review, questionnaire results analysis, and a logit regression model were used to verify the hypotheses.

Findings: 1. Nearly 80% of the respondents would like to replace their heat source, but only 20% are considering ecological heat pumps; 2. People with more knowledge about renewable sources, who are more concerned about the environment and live in older houses, are more likely to replace their heat sources; 3. The high cost of purchasing a new appliance, low subsidies or lack thereof, and the fear of rising bills are the main factors slowing the transition; 4. Higher subsidies increase the number of people willing to replace their heat sources, with the median expecting at least a 50% replacement subsidy regardless of the price of the appliance.

Implications/Recommendations: The results of the study can be used by decision-makers when formulating and adapting support programmes for people replacing old and inefficient solid fuel boilers.

Contribution/ Value Added: The research results indicate the issues that have not been formulated in the literature so far, regarding the factors determining the willingness to replace old fossil fuel boilers. The added value of this article is the indication of statistically-significant variables such as the age of the house, knowledge about renewable energy, and attitude to the environment, which affect the willingness to replace.

Article classification: research article

Keywords: heating transformation, low-stack emissions, single-family houses, preference analysis

JEL classification: Q42, Q56, R11

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Introduction

The importance of phasing out coal-fired heating systems is underscored by the fact that Poland's air quality is generally poor, as noted, among others, by the European city air quality viewer (EEA 2021), which identifies a number of Polish cities where the levels of PM2.5 exceed WHO standards. According to current guidelines, the maximum average annual PM2.5 concentration should not exceed 5 $\mu g/m^3$ (WHO, 2022b). In 2017, the figure for Poland was 23 $\mu g/m^3$; Poland thus ranked fourth among the European Union countries with the worst air quality (Adamkiewicz & Matyasik, 2019). In 2021, the average PM2.5 concentration in Poland exceeded the annual WHO guideline 3.8 times (IQAir, 2022).

A major contributor to air pollution is low stack emissions caused by the combustion of solid fuels (mostly coal and wood) by households and small manufacturing facilities (Adamkiewicz et al., 2021). Households that use fossil fuels for heating purposes are largely responsible for these emissions, which are particularly evident during the heating season (Frankowski & Herrero, 2021). According to recent data, 55% of households still use solid fuel boilers, more than half of which are old, low-grade, and predominantly coal-fired appliances (GUNB, 2022). In Poland, air pollution has a number of negative consequences, including lower health quality and a nearly three-year reduction in life expectancy (EEA, 2019). Moreover, studies show that it costs the domestic economy between 40 and 120 billion PLN annually (Adamczyk et al., 2017).

The literature lacks research explicitly devoted to the factors that account for the limited interest in switching from solid fuel heat sources to more environmentally-friendly ones. In Poland, most studies similar to those conducted by the authors of this paper have been produced by the Polish Smog Alert (Adamkiewicz et al., 2021; Pytliński, 2016; Pytliński et al., 2021; Wietrzny & Dworakowska, 2019). Dąbrowski (2022) demonstrates how coal consumption policies affect PM2.5 emissions, whereas other studies focus on the impact of anti-smog resolutions on coal consumption (Stala-Szlugaj, 2018) and low stack emissions (Flaga-Maryańczyk & Baran-Gurgul, 2022). An examination of reasons for replacing solid fuel boilers, including those cited by the beneficiaries of programmes promoting the transition to clean heat sources, revealed that households were hesitant to abandon solid fuel heating mostly due to the perceived uncertainty about future energy prices and supply availability (Frankowski & Herrero, 2021). The vast majority of studies address the impact of low stack emissions on the health of residents (e.g. Kowalska, 2020; Traczyk & Gruszecka-Kosowska, 2020; Zieliński et al., 2018).

Although the research reported in this paper clarifies and expands on certain topics previously covered in the literature, its findings are extremely relevant given the current energy crisis enhanced by the conflict in Ukraine. Identifying the disincentives to energy transition, as well as the current scale of the problem, may thus prove to be of interest to policymakers.

The aim of this article is to investigate the factors that affect the use of coal by single-family house occupants in Poland. Four research questions were proposed to this end:

1. What percentage of households that use solid fuel boilers do not intend to replace their heat sources?
2. What factors affect people's willingness to replace their heat sources?
3. What factors are the most likely to prevent people from replacing their heat sources?
4. What subsidy levels would effectively induce people to replace their solid fuel boilers?

Questions (1) and (4) will be addressed using the existing research (Pytliński, 2016; Pytliński et al., 2021; Zaborowski & Walczak, 2018), whereas answers to (2) and (3) are intended to

complement the existing state of knowledge. In this way, we set out to show not only how many people are willing to replace their heating systems but also what factors affect their attitudes. To that end, we shall review the selected literature and data from our CATI survey of 1007 households, 432 of which stated that they heated their homes with a solid fuel boiler. This paper is structured as follows: (1) Introduction; (2) Literature review on research into the use of coal boilers and low stack emissions; (3) Description of the research methods; (4) Presentation of the survey results and statistical analysis, and discussion with particular focus on measures that should be taken to reduce low stack emissions; (5) Conclusions.

Literature review

In Poland, more than 10 million tonnes of coal are burned each year by households – mainly by a large proportion of the 5.5 million existing single-family houses (Łukaszczyk, 2018). A number of studies in the literature address the relationship between the use of solid fuels and local air quality (Mamica, 2022; Wierzbińska & Adamus, 2020).

The replacement of a large number of solid fuel boilers before to the 2017–2018 heating season resulted in improved air quality in Kraków, with a marked decrease in the average PM10 and PM2.5 levels (Rataj & Holewa-Rataj, 2020). It is worth noting that clean air is one of the three main goals of the Energy Policy of Poland until 2040 strategy, which also include a fair transition policy and a zero-carbon energy system. The primary goal of the strategy is to transform the heating sector (district and individual heating systems), electrify transportation, promote zero-emission and passive housing. The strategy identifies a number of actions that, if implemented, should eventually solve Poland's air pollution problem. The following objectives are set forth in the strategy: increasing the number of efficient district heating systems; investment in heat pumps and electric heating; a shift away from household coal combustion (by 2030 in cities, by 2040 in rural areas); improving the energy efficiency of buildings and moving towards zero-emission transportation by 2030 in cities with populations of more than 100,000 (Ministry of Climate and Environment, 2021).

In order to reduce low stack emissions, it is critical to stop using solid fuels to heat buildings. Heat pumps appear to be a viable option in this regard. A recent study found that switching to a heat pump (or gas heating) without considering thermal retrofit reduces the amount of particulate matter and benzo(a)pyrene emissions produced by households by nearly 100%. Another method of lowering stack emissions is to improve thermal insulation, which can reduce emissions by 65% per dwelling while also significantly lowering seasonal heating expenses. It should be taken into account that the replacement of coal boilers, and thermo-modernisation also leads to a reduction in CO_2 emissions (Mamica, 2022).

Low stack emissions are the most significant contributor to smog (Kazmierska-Patrzyczna, 2022). In 2018, the Clean Air Programme was launched with the primary goal of supporting the replacement of 3 million off-grade boilers and performing thermal upgrades. The programme has a budget of €22.4 billion and its targets should be achieved within ten years (Blazy et al. 2021). Subsidies, however, are only one tool for addressing the issue. Adoption of anti-smog resolutions or laws, such as prohibiting the use of low-efficiency solid fuel boilers in a specific area, is another. In early 2017, the Małopolska region passed the first anti-smog resolution, which outlined the requirements for household solid fuel boilers and placed restrictions on the type of fuel that could be used (Polish Smog Alert, 2022). In 2019, a total ban on solid fuels for heating was

enacted by Kraków, and by January 2021, 14 out of Poland's 16 provinces had introduced similar anti-smog measures (Polish Smog Alert, 2022).

Despite these measures, one of the factors impeding the transition to low-carbon sources was the lack of reliable information on the types of heating systems actually used by households (Pietras-Szewczyk, 2021). Until recently, it had primarily been based on various types of estimates, including those by Pytliński (2016), Pytliński et al. (2021), Zaborowski and Walczak (2018). Since 1 June, 2021, however, all property owners and managers in Poland have been required to report the heat sources they own and use to the Central Emission Register of Buildings (CEEB). As of 24 November, 2022, 33% of the 9 million CEEB entries comprised solid fuel boilers with manual or automatic feeders, 6% coal boilers, 5% solid fuel masonry heaters/stoves, and 11% fireplaces, freestanding iron stoves, and solid fuel air heaters. A quick calculation reveals that approximately 55% of the surveyed households still use solid fuel (coal being by far the predominant one). Furthermore, more than half of the solid fuel boilers (51.4%) are rated as low-grade or off-grade (i.e. below class 3; cf. GUNB 2022). The types of heating fuels included in the CEEB demonstrate unequivocally that more needs to be done to address the issue at hand. Several studies show that individuals' quality of life is severely impacted by poor air quality (Kowalska, 2020; Traczyk & Gruszecka-Kosowska, 2020; Zieliński et al., 2018).

Table 1. Cities in Poland with annual mean PM2.5 emissions above 20 μg/m^3 in 2021

City	EEA Ranking (total 344)	Mean annual concentration of PM2.5 (μg/m^3)
Nowy Sącz	344	26.8
Zgierz	337	22.5
Łomża	336	22.4
Gliwice	335	22.1
Żory	334	22.1
Katowice	329	21.4
Piotrków Trybunalski	328	21.3
Kalisz	325	20.8
Kraków	324	20.8
Kielce	323	20.7
Bielsko-Biała	322	20.7
Lublin	321	20.4

Source: own study based on EEA (2021).

Numerous studies have demonstrated that particulate matter (PMx) has an extremely negative impact on human health (Adamkiewicz et al., 2021). Ambient air pollution has been identified as a significant environmental health risk factor, contributing to the premature death of approximately 4.2 million people each year (WHO, 2022a). It reduces life expectancy by 2.8 years in Poland, and by 2.2 years in Europe (EEA, 2019). According to studies, Poland may be losing up to 120 billion PLN per year as a result of hospital admissions and missed workdays by people whose health has been adversely affected by exposure to particulate matter and benzo(a)pyrene (Adamczyk et al., 2017). Table 1 shows the most polluted cities in Poland by PM2.5. In as many as 12 of them, air pollution exceeds 20 μg/m^3 (by comparison, the current WHO standard is 5 μg/m^3; cf. WHO

2022b). The table clearly shows that the problem with PM2.5 air pollution mainly affects Poland and Italy, as well as a handful of cities in Croatia, Bulgaria, and the Czech Republic (EEA, 2021).

It should be emphasised, nevertheless, that low stack emissions can vary in nature and are affected by a variety of factors depending on the locality. PM2.5 is merely one of several dangerous substances that contribute to smog. Others include nitrogen oxides, PM10, and PAHs (polycyclic aromatic hydrocarbons), which are primarily the side effects of road transportation (Adamkiewicz & Matyasik, 2019).

Research methodology

The analysis relies on data from a CATI survey conducted in July and August 2021 among a random sample of individuals who own or live in single-family homes in Poland. Since approximately half of the country's population lives in single-family houses and more than half still use solid fuel boilers, the selection of this group appears justified; additionally, respondents came from all over the country, hence the survey can be considered representative. The questions (yes/no, single-choice, multiple-choice, and open-ended) addressed various aspects of energy transition, such as self-assessment of the respondents' knowledge, attitudes, behaviours, and plans to implement energy-saving measures. A total of 1007 responses were collected, of which 432 homeowners were selected who marked one of the following as their main heat source: 1. solid fuel boiler (coal, wood or biomass) with a manual feeder; 2. solid fuel boiler (coal, wood or biomass) with an automatic feeder; 3. solid fuel masonry heater/tiled stove (coal, wood or biomass); 4. coal-fired stove/boiler. The list of heat sources was taken from the form that residents were obliged to complete for the CEEB. For the purpose of this study, 12 survey questions were used.

The study aimed to determine whether people who use solid fuel boilers are open to switching to another heat source as well as what factors affect their willingness to do so. To this end, the following research hypotheses were formulated, which correspond to the research questions mentioned above:

H1: The vast majority of households using solid fuel boilers are considering switching to another heat source,

H2: Their willingness to replace solid fuel boilers is affected by several statistically-significant factors,

H3: The main impediment to replacing the heat source is its cost,

H4: The anticipated amount of subsidy is critical in deciding whether or not to purchase a new heat source.

In order to test these hypotheses, descriptive statistics were analysed for both the respondents and the buildings in which they live. A logit regression model was also used in the study. In the final stage of our investigation, we looked at the most effective level of subsidy for replacing the heat source.

Results and Discussion

Table 2 shows the survey participants' demographics, including gender, age, education, and labour market status, as well as the period of time in which their house was completed. The survey participants were also asked about their self-assessed level of environmental awareness and familiarity with renewable energy sources, since these two factors were considered likely

Table 2. Descriptive statistics of the studied population, including awareness of environmental issues and familiarity with RES

Feature	Specification	N	Percentage
Gender	Male	168	38.89
	Female	264	61.11
Age bracket	Below 25	55	12.73
	25–34	139	32.18
	35–44	103	23.84
	45–54	75	17.36
	55–64	155	35.88
	65 or more	20	4.63
Education	primary	7	1.62
	lower secondary	6	1.39
	basic vocational	55	12.73
	secondary	189	43.75
	Higher	175	40.51
Labour market status	private sector employee	190	43.98
	public sector employee	81	18.75
	self-employed	30	6.94
	farmer	14	3.24
	student	29	6.71
	pensioner	41	9.49
	unemployed and others	47	10.88
House completed (in)	before the 1980s	133	30.79
	the 1980s	67	15.51
	the 1990s	81	18.75
	2000–2010	80	18.52
	2010–2020	62	14.35
	after 2020	9	2.08
Awareness of environmental issues	very high	196	45.37
	high	147	34.03
	average	75	17.36
	small	8	1.85
	very small	6	1.39
Familiarity with RES	very high	72	16.67
	high	155	35.88
	average	171	39.58
	small	30	6.94
	very small	4	0.93

Source: own study based on CATI results.

to affect their willingness to switch to more ecological heat sources. For this reason, they were included in analysis.

Most survey participants were female (61.11%). The 55–64 age bracket was the most numerous (35.88%), followed by those aged 25–34 (32.18%). More than 40% of survey participants worked in the private sector, with public sector employees coming in second. Over 80% of the respondents had a university degree or completed secondary education. About 3% had primary or lower secondary education. The largest group in the survey was made up of people living in houses built in the 1990s, and between 2000 and 2010, respectively (both over 18%). The smallest group lives in houses built after 2020 (2.08%). More than three-quarters of those surveyed said they cared or cared a lot about the environment with only 4% reporting little or no awareness of environmental matters. The largest group (39.58%) considered their familiarity with renewable energy sources as average, whereas 35.88% claimed to have extensive knowledge of RES.

Willingness to replace solid fuel boilers

When asked whether they would be prepared to switch from their current heat source to another, the respondents were also requested to indicate what kind of appliance they would like to replace it with (cf. Figure 1). Seventy-seven per cent of the respondents were open to this possibility, but 18% declared their intention to purchase a biomass boiler (i.e. one that uses wood pellets as fuel). Switching from, for instance, a low-grade coal boiler to a modern biomass-fired one was viewed as a positive development, since our study focused on generally conceived readiness to replace. However, even though pellets can be seen as an improvement on coal, they only reduce rather than resolve the issue of pollution. The same can be said for gas, which is currently regarded as a transitory energy source. The latter option was chosen by 22% of the respondents, a further 20% opted for heat pumps, widely regarded as the most promising and environmentally-friendly solution, while 9% contemplated switching to electric heating.

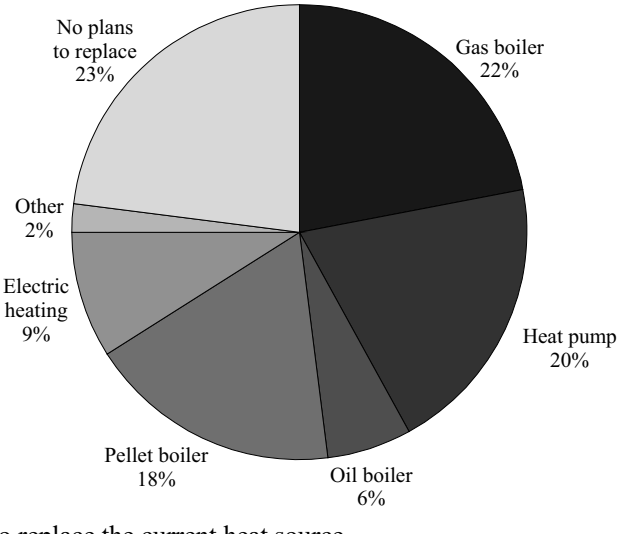

Figure 1. Willingness to replace the current heat source

Source: own study based on CATI results.

As a result, despite their willingness to replace their heat source, only about 30% of the survey respondents are thinking about switching to a zero-emission fuel, with the remainder viewing it as a more temporary solution. However, it should be noted that converting to gas, for example, would significantly alleviate the problem of low stack emissions in Polish cities, and as such is regarded as desirable from the perspective adopted in this paper.

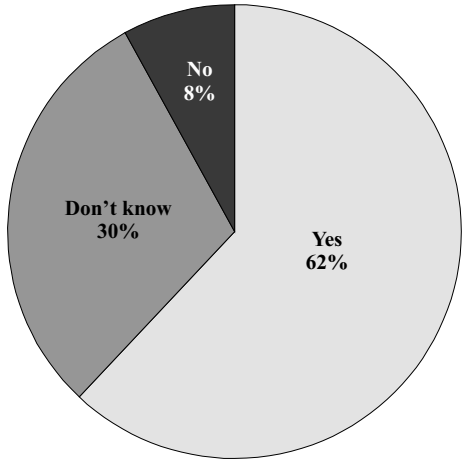

Figure 2. Willingness to switch to an environmentally-friendly heat source under duress

Source: own study based on CATI results.

Further, the respondents were asked whether they would install a heat pump or a solar panel-assisted heat pump if they were forced to abandon their current solid-fuel heating system. As many as 62% said they would replace it, 30% said they did not know, whereas only 8% responded in the negative.

Factors that affect the willingness to replace solid fuel boilers

In the next stage of the analysis conducted in this study, a logit regression model was developed (logit regression allows the prediction of a future outcome based on a set of predictor variables).

In our study, the regression is given by the formula:

$$Y_i = \beta_0 + \mathrm{Sex}_i + Age_i + Education_i + Job + Houseage_i + Environmentalawareness_i + \\ + FamiliaritywithRES_i + \varepsilon_i \quad (1)$$

The willingness to replace coal heating with an alternative energy source was the dependent variable (with 1 denoting the willingness, whereas 0 unwillingness to replace). Explanatory variables included the time period in which the house was built; gender and age of house occupants; their education, occupational status, environmental awareness, and familiarity with renewable energy sources. The amount of subsidy had no effect on the decision to replace, as confirmed by the Wald test (Bursac et al., 2008). Our analysis thus focused on the factors shown in Table 2.

The estimated logit regression model is correct. The model itself is statistically-significant, which was attested by the likelihood ratio chi square statistical test, with 37.60 for 7 degrees

of freedom (information criterion AIC 551). To check how the model fit the data, we calculated the pseudo R (McFadden), which was 0.062, whereas the Cox and Snell pseudo R was 0.12. These low values may indicate a poor data–model fit, which may be due to the relatively small number of observations (Greene, 2003). However, the Brier score, which measures the accuracy of probabilistic predictions, was 0.21. Such a low score confirms that the predictive value of the model is good (Brier, 1950). Taking into account the three different measures of estimation, we can consider our model to be correct.

Table 3. Logit regression model for 7 studied variables

	Variable	Estimate	Std Error	z value	Pr(>|z|)	Odd Ratio
β_0	Intercept	–2.263	0.847	–2.672	0.008	0.104
β_1	Gender	–0.058	0.221	–0.260	0.795	0.944
β_2	Age	–0.085	0.084	–1.011	0.312	0.919
β_3	House age	–0.172	0.072	2.390	0.017	1.188
β_4	Education	–0.223	0.295	–0.757	0.449	0.800
β_5	Ecological awareness	0.468	0.126	3.706	0.000	1.597
β_6	Job	0.039	0.218	0.177	0.860	1.040
β_7	Familiarity with RES	0.286	0.130	2.188	0.029	1.331

Source: own study based on CATI results.

Accordingly, the statistically-significant variables that affect the decision to replace the heat source are: 1. the age of the house; 2. the occupants' environmental awareness; and 3. the occupants' familiarity with renewable energy sources. Because the *p* is greater than 0.05, the remaining variables, such as the respondents' gender and age, occupation, or education, are not statistically-significant. As a result, these factors have no bearing on the decision to replace the heat source in this survey. The crucial factors in order of significance were environmental awareness, familiarity with renewable energy sources, and the age of the house. The greater the age of the house, environmental awareness, and familiarity with RES, the greater the willingness to replace the heat source.

Disincentives to replace solid fuel boilers

Next, we attempted to estimate which factors have the greatest negative impact on people's readiness to switch to a different heat source. For this purpose, we selected 10 factors that, in our opinion, were most likely to affect energy transition in Poland. These factors are shown in Figure 3 along with the percentage of people who feel that a particular one has a negative impact on their decision to replace their solid fuel boiler.

High costs of purchasing a new appliance (69.4%); little or no subsidy (66.8%); concern about higher bills (56.5%); lack of knowledge of full purchase and running costs (54.4%); complicated installation process (53%); complicated subsidy application procedure (45.1%) were mentioned as disincentives to replace the heat sources. The least popular responses were: negative feedback from others and the belief that replacing the heat source has no effect on air quality. Thus, more than 60% of people recognise that the type of heating they use affects air quality, and more than 60% are unconcerned about negative feedback from others, which is a positive trend.

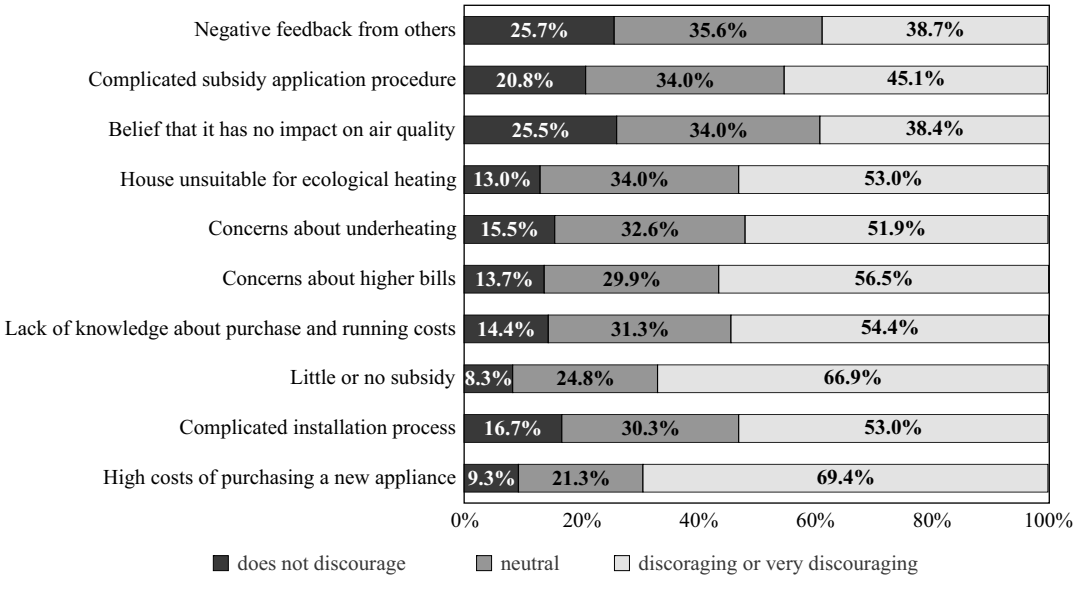

Figure 3. Disincentives to replace the current heat source

Source: own study based on CATI results.

It should be noted that replacing a heat source is very expensive; in fact, three of the most significant disincentives are financial in nature.

Expected subsidy levels

The final section of the survey focused on hypothetical subsidy levels expected to induce single-family households to replace their solid fuel boilers. To that end, two questions were asked about the anticipated subsidy levels for appliances worth 20,000 PLN and 40,000 PLN, respectively, which reflect the various purchase and installation costs. Figures 4 and 5 show the final results.

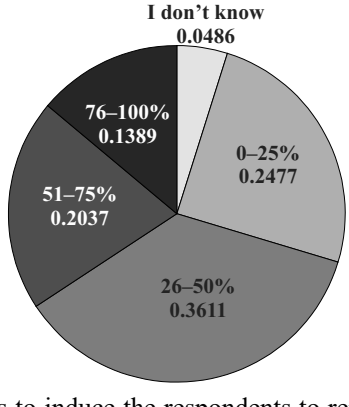

Figure 4. Expected subsidy levels to induce the respondents to replace their heat source if the total replacement cost was 20,000 PLN

Source: own study based on CATI results.

Almost a quarter of those surveyed would like to receive a replacement subsidy of up to 5,000 PLN with the optimal amount around 26–50% of the total replacement cost. Interestingly, 27% of the respondents put the optimal subsidy at 50% of the total cost. Only 13.89% expected a subsidy greater than 15,000 PLN, with 8% expecting the subsidy to cover all the expenses incurred. Almost 5% of the respondents were unable to specify the preferred amount. It should be noted that if the hypothetical subsidy did not exceed 25%, only one-quarter of the survey participants would be interested; however, if it was increased to 50%, the interest rose by 36%. By comparison, a 75% subsidy translated into an additional 20% increase. Finally, if the subsidy covered all the costs, a further 14% of the respondents would consider replacing their heat source.

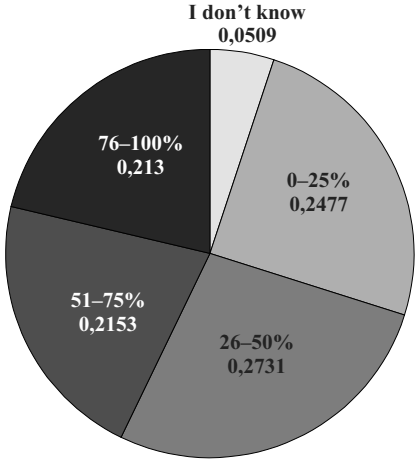

Figure 5. Expected subsidy levels to induce the respondents to replace their heat source if the total replacement cost was 40,000 PLN

Source: own study based on CATI results.

Table 4. Hypothetical subsidy statistics

	Subsidy (PLN)	
	20,000	**40,000**
Mean	9,481	20,066
Median	10,000	20,000
Mode	10,000	20,000

Source: own study based on CATI results.

If the total replacement cost was 40,000 PLN, the responses are more evenly distributed. Nearly a quarter of the respondents would like to receive a subsidy of up to 10,000 PLN, however, most expected a 26–50% subsidy. In this group, 15% expected a subsidy of 20,000 PLN, almost 22% expected more than 30,000 PLN, and a further 6% wanted the subsidy to cover all the replacement costs. More than 5% of the survey participants were unable to specify the optimal subsidy amount. It should be noted that if the subsidy covered up to 25% of the costs, only a quarter of those surveyed would consider replacing their heat source, whereas if the subsidy increased to 50%, the interest increased to 27%. Upping the subsidy to 75% resulted in another increase, this

time of 21%. A further 21% of the respondents would consider replacement if the subsidy level was increased to 100%. Accordingly, it is possible to conclude that the level of subsidy affects the willingness to replace the heat source: the higher the proposed subsidy, the more people are willing to switch to another, more environmentally-friendly heat source.

Comparison of research results with the existing knowledge in the literature

A number of authors attempted to estimate the percentage of households interested in replacing their heat source. In a study conducted among residents of single-family houses by Pytliński et al. (2021), as many as 48.2% stated that they had no plans in this regard. Switching to gas was considered by the second-largest group (17.4%), followed by coal-fired boilers (8.6%), pellet boilers (8.3%), heat pumps (5.4%), and electricity (3.7%). In contrast, according to another, slightly less recent study, as many as 78% of those surveyed stated that they did not intend to replace their heat source in the near future, fewer than 12% only wanted to replace their coal boiler with a more efficient one, whereas nearly 7% considered switching to gas heating. Fewer than 1% of the respondents stated that they planned to switch to environmentally-friendly sources, such as heat pumps (Zaborowski & Walczak, 2018). The authors of the cited study also inquired about a five-year perspective – if boilers had to be replaced due to poor air quality – and found that more than 47% of the respondents would be able to do so within this time frame if the cost did not exceed 8,000 PLN (Zaborowski & Walczak, 2018). A very similar response structure was reported in a survey of occupants of single-family houses in the Małopolska region, where more than 77% of the respondents declared that they were not planning to replace their coal boilers, more than 10% showed interest in switching to gas, whereas 7% intended to upgrade their old gas boilers. In the cited survey, ecological heat sources were chosen by fewer than 2% of the participants (Pytliński, 2016). By contrast, in our survey, approximately 23% of the respondents declared that they had no plans to replace their heat source, switching to gas was planned by 22% of the respondents, whereas as many as 20% chose heat pumps. Despite the varying responses and percentage breakdowns, a number of conclusions can be drawn from all of the preceding studies.

First, popular awareness of the importance of air quality is increasing (Białynicki-Birula et al., 2022; CBOS, 2019, 2021). As a result, it appears that the more recent the research, the greater the interest in heat pumps and, more broadly, heat source replacement. Environmental awareness aside, the existing support programmes and anti-smog resolutions may affect people's willingness to replace/upgrade or even trigger the entire process. It is worth noting that the proportion of the respondents who chose heat pumps is higher in the study reported in this paper than in research published two years ago (Pytliński et al., 2021), which may be due to the fact that the said programmes (such as Clean Air) have been in place long enough to be noticed.

Second, a sizeable proportion of the respondents in each of the discussed studies were considering switching to gas heating. It would be interesting to repeat these surveys in the current situation, i.e. after the outbreak of war in Ukraine, to see if these figures have decreased. Another intriguing finding is that a subset of participants in each study preferred to continue using solid fuels for heating, even though they were willing to upgrade their current appliance to a more efficient one.

Our research also uncovered a number of factors that discourage people from replacing their current heat source, with financial concerns playing a major role. Nearly two-thirds of the respondents felt that the proposed subsidy levels were insufficient. The existing literature implies that subsidies have a significant impact on people's decisions in this respect. With a subsidy

of 30%, 46% of those surveyed would be willing to replace their heat source, with a 50% subsidy the number increases by 13%, while a 70% subsidy adds another 12% to the pool (Pytliński, 2016). Aside from purely financial factors, the lack of knowledge, the complexity of the installation process, and bureaucratic constraints all have a negative impact on willingness to upgrade.

A number of studies deal with factors that affect people's willingness to pay extra for green electricity (Hojnik et al., 2021; Kowalska-Pyzalska, 2019; Mamica, 2021; Zorić & Hrovatin, 2012) or clean air (Dong & Zeng, 2018; Guo et al., 2020). They all emphasise the importance of environmental awareness and attitudes as determinants of willingness to contribute to the costs of energy transition (Kowalska, 2020). This relationship is also supported by our research, but in the context of upgrading heat sources. Furthermore, our findings suggest that people living in older houses are more inclined to replace their heat sources, which, according to the authors of this paper, may be due to higher heating bills caused by the poor performance of current thermal insulation. However, in order to confirm this hypothesis, additional research would need to consider a variety of energy efficiency improvements in this specific segment of the housing stock.

In view of the foregoing, the authors of this paper believe that priority should be given to:

- adjusting subsidy levels in support programmes to current prices (i.e. taking inflation into account),
- removing bureaucratic obstacles,
- promoting RES and expanding knowledge of their positive impact on the environment,
- promoting support programmes so that as many people as possible are aware of their existence.

Conclusions

Low stack emissions are unquestionably a serious issue that must be addressed effectively, particularly in view of recent decisions to extend the deadlines for phasing out all coal-fired heating systems, which will likely have a significant impact on air quality during the current heating season, including in the Małopolska region. Concerns about what would be burned in boilers this winter have long been a media topic, as researchers discover more and more links between air pollution and declining health (Kowalska, 2020; Traczyk & Gruszecka-Kosowska, 2020; Zieliński et al., 2018).

In Poland, households that use solid fuel (especially coal) for heating purposes are primarily responsible for low stack emissions. In order to solve or mitigate the severity of this problem (as well as issues with coal supply caused by restrictions on imports from Russia), it is critical to replace the old and inefficient coal boilers with heating systems based on heat pumps or electric boilers. To accomplish this, support programmes must be tailored to the needs and expectations of those who continue to use solid fuels; moreover, increased public awareness initiatives about energy efficiency and air quality are required. In-depth knowledge of potential heat sources and how they work should be disseminated more broadly. The analysis of a representative group of single-family house occupants reported above allows important conclusions about current heating systems and preferences for change to be drawn. The most important findings that correspond to the research questions and hypotheses presented in this paper are as follows:

Almost 80% of the respondents expressed interest in replacing their heat source. Approximately 60% of them want to upgrade their current boiler, but prefer to continue using solid fuels. Heat pumps and electric heating proved to be the least popular, whereas gas boilers and pellet boilers were the most common alternatives. However, switching from coal to gas or increasing the use of pellets should result in a significant reduction in low stack emissions per household.

According to logit regression analysis, the following factors influence people's willingness to replace boilers: the age of the house, environmental awareness, and knowledge of renewable energy and heat sources. The strongest correlations were found among those respondents who declared a high level of environmental awareness. Those who were more familiar with renewable energy sources and lived in older buildings were also more likely to consider upgrading their heating systems (as the current ones are likely to generate high bills). The other variables studied, such as gender, the respondents' age, employment status, and educational level, proved to be statistically-insignificant.

The high costs of purchasing a new appliance, little or no subsidy, and the fear of rising bills are the main deterrents to replacing a solid fuel boiler. The respondents frequently mentioned all of these, which means that financial factors constitute the most significant impediment to heating transition in Poland. Other barriers include a lack of familiarity with full purchase and operating costs, a complicated installation process, a failure to adapt the home to the needs of ecological heating, and a fear that the new heat source will not provide full thermal comfort. The final factor of note was the complexity of the subsidy application process. Knowledge-related issues should thus be recognised as another significant obstacle.

The expected subsidy levels are comparable regardless of the purported cost of the new appliance. A 50% subsidy towards replacement costs is most commonly expected based on the median and the dominant; likewise, only about 5% of those surveyed in both cases are unable to specify the level of subsidy that would encourage them to switch from a solid fuel boiler. In the less expensive scenario, approximately 14% of those surveyed expect a subsidy of 76–100%, whereas in the more expensive one, the percentage of those anticipating the highest possible subsidy rises to over 21%. According to the findings, the higher the subsidy, the more people are willing to replace their heat source. In both the examined scenarios (i.e. 20,000/40,000 PLN), each increase in subsidy results in more people expressing interest in replacing their heat source.

The analysis contained in this paper presents general conclusions, without taking into account the specific needs of people in a difficult financial situation. Future research should focus on separating those who are energy-poor from those who can afford to replace their heat source but for various reasons do not.

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