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Problems and prospects of thermal modernization of farm buildings in rural areas in Poland

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Abstract

Background Thermal upgrading is an important element in the economic transformation of Poland towards a low-emission economy. This paper presents the results of research into the current status and plans of inhabitants of rural areas in Poland with regard to thermal upgrading of residential buildings and other buildings used in the agricultural activity of the study participants. The main purpose of the article is to identify thermal modernization needs and to analyse factors influencing individual thermal modernization plans in terms of replacement or modernization of heating systems. A key element of the analyses was the issue of upgrading priorities and the dependency between declared intentions in terms of thermal upgrading work and the production and economic features of the farms studied.

Results The main research material were surveys conducted with a randomly selected sample of 480 farming households in Poland. The analyses used, amongst others, multiple correspondence analysis (MCA) to determine and assess the relationships between the variables studied. Detailed correspondence analysis shows that there are strong dependencies between plans for thermal upgrading of farm buildings and the system of agricultural production ($\varphi^2 = 0.1503$), the economic size of farms ($\varphi^2 = 0.1100$), and the location of farms ($\varphi^2 = 0.0947$).

Conclusions The research showed that there is a need for thermal upgrading in the examined area of study, especially with regard to the replacement or modernisation of heating systems. The issue of thermal upgrading of residential and farm buildings in rural areas in Poland requires support and engagement at all levels of administration, as well as the modernisation of assistance programmes.

Keywords Thermal modernization, Agriculture, Livestock buildings, Residential buildings, Multidimensional correspondence analysis (MCA), Poland

Introduction

The global energy system is undergoing a profound transformation, which is driven by the need to decarbonize the energy system. In this respect, it is necessary to reduce the production of fossil fuels and accelerate the implementation of low-emission energy technologies. It is estimated that renewable energy can meet two-thirds of the total global energy demand and contribute to the significant reduction in greenhouse gas emissions that is necessary by 2050 to limit the average global surface temperature increase to below 2 °C [23]. The transformation processes are studied both theoretically and empirically and considered multidimensionally. For example, Blondeel et al. [7] write about two dimensions, i.e., a set of "high-emission" energy transformations associated with the phasing out of fossil fuel consumption and "low-emission" energy transformations that are related to the development of new renewable energy and other low-emission

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technologies. Apart from defining different dimensions and sets, challenges can be distinguished at the global, transnational, national, regional and local levels. Macro changes are based on actions taken at the micro level, i.e., at the level of households and enterprises. Macro effects ultimately depend on microeconomic decisions made by individual households, farmers and enterprises.

On a global scale, the European Union in particular has consistently strived for many years to minimize its impact on the environment, use resources more sustainably, and reduce greenhouse gas emissions. There is a visible upward trend in the share of electricity production from renewable sources (RES) in the European Union countries [14]. In relation to the energy transformation, the rapid decarbonization of heat remains an ambitious priority of energy and climate policy. Heating and cooling constitute around half of the EU energy consumption (https://energy.ec.europa.eu/topics/energy-efficiency/heating-and-cooling_en). In Europe, the building stock accounts for approximately 36% of energy-related greenhouse (GHG) emissions [43]. Although heat decarbonization is a challenge in many countries, it is particularly important in countries that still rely on systems based on fossil fuels (such as Poland) [4]. Minimizing energy consumption in buildings is a key element in designing effective energy policies and supporting the transition to sustainable energy systems [19]. Not only in the European Union, but also in the United States, Canada, and China, among the others, more stringent building policies have improved the way energy is used [49].

Designing the right kind of political and governance architecture [64], as well as appropriate scenario planning and implementation of transformation solutions in relation to local energy systems are important in the context of stimulating transformation [38]. Also, the importance of decisions made at the microeconomic level should be emphasized. As Panos et al. [51] point out—"*Households are at the heart of the energy transition*". Moreover, we are currently in the process of energy transformation, which is supported by the social demand for a change in the energy paradigm. The current transformation also includes ecological motivations [59]. As Becker et al. [4] emphasize, understanding public opinion and accepting low-emission heating systems is a key element in the successful introduction of alternative solutions. There are many market and behavioural barriers that have not been adequately addressed in energy efficiency policies and programs [70].

The subject of this work focuses on issues related to thermal modernization. Thermomodernization is an important and topical issue in rural areas in Poland [54]. To a large extent, especially small farms, require financial support to improve energy performance and ensure energy modernization. Thermal upgrading of buildings involves design, construction and installation work that results in a reduction of the thermal energy requirement for heating and cooling properties and domestic hot water. Thermal modernisation of buildings can effectively increase the energy efficiency of buildings. The thermal modernization process results in the energy costs reduction. On the other hand, one of the biggest problems is the issue of individual financing of investments in this area. The thermal modernization is widely recognised as a key process for achieving various societal objectives related to environment and climate protection. The thermal modernisation of buildings is necessary for improving energy efficiency and reducing emissions of pollutants into the atmosphere [69]. Thermal upgrading is key in terms of limiting the negative impact on the environment (e.g., by eliminating solid fuel boilers). One of the main causes of low air quality is low-level emissions, which are formed not far above the ground (up to 40 m) [2]. Research results on the possible environmental benefits of thermal upgrading of residential homes for the south of Poland have been presented, among others, by Blazy et al. [6].

The area of increasing energy efficiency is a key element of the European Union's policy. The basis of this policy is the new directive on energy efficiency [16]. The overarching goal of the new EU regulations in the area of energy efficiency is to reduce final energy consumption by 11.7% compared to the energy consumption in the EU in 2020. All EU member states will have to achieve an average annual energy savings rate of 1.3% in 2024–2025, then 1.5% in 2026–2027 and 1.9% in 2028. Energy efficiency is considered an important factor in achieving various environmental and climate protection goals, which has been reflected in the EU's policy on the European Green Deal. The European Union (EU) has introduced energy and climate policy strategies and measures intended to increase energy efficiency in various sectors. The European Green Deal strategy (European Commission 2019) recognises that energy efficiency is needed to achieve the EU's long-term objective of net-zero GHG emissions by 2050, as defined in the European Climate Law [20, 45]. From the point of view of Polish legislation, it is advisable to mention the Act of 21 November 2008 on supporting thermal modernisation and renovations and on the central register of building emissions. This Act introduced several key changes and support mechanisms in the field of financing thermal modernisation and renovation projects (thermal modernisation and renovation bonuses and grants for renewable energy installations). A system for registering buildings in terms of their emissions was also introduced, which is aimed at monitoring and reducing pollutant emissions.

The main purpose of the article is to identify thermal modernization needs and to analyse factors influencing individual thermal modernization plans in terms of replacement or modernization of heating systems. A key element of the analyses was the issue of upgrading priorities and the dependency between declared intentions in terms of thermal upgrading work and the production and economic features of the farms studied. The study focused in particular on thermal upgrading intentions declared by respondents (to be completed by 2025, and after this deadline).

This article is made up of several parts, with reviews of the relevant literature in this field, research methodology, and data sources presented after the introduction. The results of the empirical research are then presented and discussed. The article ends with a summary containing the most important conclusions and the perspectives for future research in this topic area.

Background of the study

In practice, thermal upgrading usually involves insulating external walls, sealing and insulating roofs or ceilings, changing windows and doors, and replacement of heat sources/heating appliances (e.g., coal- or wood-fired boilers with more ecological heating sources). In the case of the latter, of key importance from an ecological perspective are, for example, investments in renewable energy sources (e.g., photovoltaic panels), the installation of heat pumps, and heat recuperation systems. Thermal upgrading not only brings obvious economic benefits in the form of lower costs [5, 18, 60]. In the subject literature, also in related research areas adopted for the needs of this study, are the results of economic analyses of fields of application, e.g., installation of photovoltaics combined with heat pumps in detached houses. The economic benefits of such solutions are shown in the results of research by Kijo-Kleczkowska et al. [36]. An important element in thermal upgrading projects is the use of renewable energy sources in the selection and use of heat sources. As shown in research by Moskwa-Bęczkowska and Moskwa [50], simultaneous use of heat pumps and solar panels in residential properties has a positive effect on annual energy requirement indicators.

Furthermore, both the modern building material industry and installation methods not only make it possible to improve heating and damp-proofing, which has an economic benefit in the form of lower heating costs, but also provide considerable freedom in terms of shape, colour and structure, which is important from a visual perspective [65]. It is worth noting here that in the heyday of residential construction in Poland, with the erection of large panel buildings from the 1960s to the 1980s, considerably less attention was placed on thermal upgrading. As noted by Runkiewicz et al. [61], this was also a period in which there was limited access to some building materials, including thermal insulation. The authors of the above-mentioned publication also noted the approximate indicators of heat energy use depending on the period in which buildings were constructed. They point out that until 1996, the indicator for the use of such energy was 240–350 [kWh/m^2], while from 1998 it was 90–120 [kWh/m^2]. On the one hand, this demonstrates the progress achieved in terms of materials, while on the other, it shows the need in terms of thermal upgrading for buildings erected, for example, in the 1960s, 1970s and 1980s.

The topic of scientific papers related to thermal upgrading usually refer to individual family homes or blocks of flats [3, 10], as well as public utility buildings [48, 63] and churches [72]. There are relatively few works into the status and perspectives regarding thermal upgrading of farming livestock buildings. In general, research that combines the issues of thermal upgrading for residential and livestock buildings in agriculture are scarce, especially in the spatial scope adopted in this article [40]. This paper conducts a comparison between implemented and planned thermal upgrading projects, both with regard to residential and farming buildings. This paper aims to fill this cognitive gap. One of the fundamental problems for rural communities in many countries is ensuring the universal satisfaction of their basic energy needs and appropriate energy standards for buildings [15, 25, 46, 55, 58].

In Poland, rural areas constitute 51.2% of the total area of the country. The importance of the issue raised in this article is underlined by the large number of farms in Poland. According to the latest general agricultural census in Poland [31], the number of farms in June 2020 was 1,317,400 (https://stat.gov.pl/). Flats and houses in rural areas have on average a larger living space than in urban areas. In rural areas there are mainly individual family homes, which is of key importance for the issue studied. First, the cost of thermal upgrading of these buildings is high, and the individual financial means at the disposal of inhabitants are not sufficient to achieve such aims. Income from agricultural activity, especially in the predominating agrarian structure of small farms in Poland, are lower than remuneration for hired work. Research by Kisielińska [37] shows that farms with 39 hectares of agricultural land provide an income greater than the remuneration for hired work. In Poland, however, more than half of farms do not exceed 5 hectares of agricultural land. Second, lack of thermal upgrading results in high building maintenance costs, including in particular heating. No less important are related issues such as dampness and other detrimental changes in buildings that can have a negative effect on the health and quality of life of residents. Meanwhile, taking into account livestock and farming buildings, it is also worth drawing attention to the issue of microclimates forming in buildings, which impacts the well-being of livestock. The issues raised are important from the point of view of energy sustainable animal production, and the basis for providing an acceptable level of comfort for animals is a suitable temperature [24]. It is important that after modernization, buildings should ensure animals a high level of well-being [62].

Rural areas in Poland are therefore places of particular importance in terms of the analysis of energy efficiency, including the current status and plans in the field of thermal upgrading. It is in rural areas that the problem of energy poverty occurs most frequently, the basis of which is the low energy standard of buildings, economic problems and insufficient knowledge and skills (e.g., relating to the use of machines and devices) [53]. Inefficient energy systems, high transmission costs to areas with lower population densities, marginalization, fuel/energy poverty, and inadequate energy services are among the problems that plague many Polish rural communities [22]. Integrating the issue of energy efficiency with broader social aims, including in particular the ever more frequent phenomenon of energy poverty, is an important topic from both a scientific and practical point of view. Of course, the relationships between energy use in food systems, food system productivity and energy resource constraints are very complex [52].

This work is part of the research on the cultural perspective on energy consumption in households. In this case, it concerns farmers' households[42]. Analyses and the increase in knowledge in this area, i.e., behaviours related to energy efficiency, are the basis for modifying intervention programs[68]. The literature on energy policy in the area of thermal modernization in Poland remains deeply focused on technical issues. In the few publications on the issues of the cultural perspective on energy consumption in households in Poland, analyses were made of the level of energy awareness in rural conditions [9], the identification of barriers in the development of the use of renewable energy sources by consumers [66] and the essence of social responsibility of consumers in the process of energy consumption [26]. So far, it has not been possible to identify factors influencing individual thermal modernization plans in rural areas, including in the area of farmers' households. Therefore, the research was undertaken, where a deeper insight into the decision-making process was obtained, in the studied thematic area, at the level of farms in Poland. The research gap in the literature on modernization needs also consists in the reliability and unity of the technical and economic data provided at the level of farms. This study aims to fill this gap.

Materials and methods

Study area

The data required to address the posed research problems was obtained using the survey method. The empirical research, the principal source of information for the needs of this paper, was conducted in Poland between October 2019 and March 2020. The research sample consisted of 480 people, which included individual farming households located in six randomly selected voivodeships in Poland. The principal assumption in this operation was the random selection of one voivodeship from each macroregion in Poland. Figure 1 presents the spatial scope of the research, taking into account the surveyed counties.

The realization of the above research was entrusted to the Agricultural Advisory Centres in the selected voivodeships in Poland, that is:

- The Dolnośląski Agricultural Advisory Centre based in Wrocław,
- The Lubelski Agricultural Advisory Centre based in Końskowola,
- The Łódzki Agricultural Advisory Centre based in Bratoszewice,
- The Małopolski Agricultural Advisory Centre based in Karniowice,
- The Warmińsko-Mazurski Agricultural Advisory Centre based in Olsztyn,
- The Zachodniopomorski Agricultural Advisory Centre based in Barzkowice.

Suitable agreements regarding the completion of the research were concluded with all the institutions mentioned above, and the survey research for the needs of this scientific project obtained a suitable recommendation

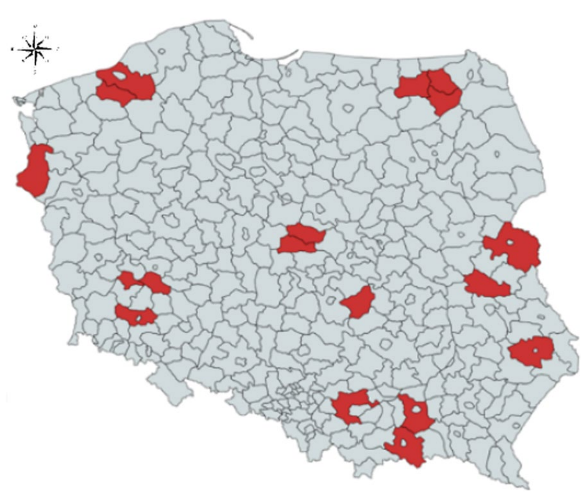


Fig. 1 Spatial extent of field studies. *Source*: Own elaboration

from the Rector's committee for scientific research ethics at the University of Economics in Wrocław (no. 57/2020). The measurement tool in the research was a questionnaire for agricultural producers that contained a total of 40 questions divided into four schematic blocks: general information about the respondent, their household and farm; the purchase and use of energy and related expenses; attitudes and habits related to the use of energy devices and the use of electrical devices. The research used a standardized questionnaire, consisting for the most part of closed questions. In the case of selecting farmers for the study, a non-probabilistic technique was used—convenience selection. The study was conducted on respondents available to the interviewer (agricultural advisor). The research was also conducted with experts, and the results of this work relating to another research problem were presented in several scientific articles.

Methods

For the purposes of this work, multidimensional correspondence analysis was conducted using Statistica 13.3 software. This method made it possible to identify the co-occurrence of many categories of variables, and is broadly used in socio-economic research, ecological research etc., including also new patterns and plans for technical and technological changes. MCA can be applied to both quantitative and qualitative data [41]. The starting point in multidimensional correspondence analysis is appropriate preparation of a set of input data. MCA requires level-coding for the data sets and relies on chi-square distance to perform its analysis. The correspondence analysis was begun by building a complex marker matrix (a Burt matrix) [1]. This provided the best explanation for the variability in the data collected. All graphs were prepared using a three-dimensional system (the highest degree of reproduction). Apart from the scientific benefits, the use of correspondence analysis may also have a practical dimension in the design and upgrade of social and economic programmes, subsidies etc.

The correspondence analysis examined the co-occurrence and dependency, including dependency strength, between plans for the replacement or upgrading of heating systems, and:

- the agricultural production system (three variants—crop production, animal production, and mixed production);
- the area of agricultural land (four categories: 5–19.99 ha, 20–49.99 ha,50–99.99 ha, 100 ha and more);
- the economic size of the farm (six categories: < 10 thous. euro SD; 10.1–13 thous. euro SD; 13.1–20 thous. euro SD; 20.1–50 thous. euro SD; 50.1–100 thous. euro SD; > 100 thous. euro SD);
- the location (six voivodeships in Poland, that is regions used in the empirical research.

Taking into account the number of variables and features, as well as the observed number of categories of features, a 22 × 22 Burt matrix was generated.

Both the research methodology (random selection, sampling frame, research sample size) and the research implementation method, including the selection of cooperation partners for the project (ODR`S) contributed to obtaining reliable and trustworthy data on, amongst others, the condition of buildings and the perspectives for changes in the field of thermal upgrading. This paper relates entirely to issues of thermal upgrading (in relation to farm buildings) and farming households (in relation to residential buildings), and the presented research results have not been published.

Results

As was mentioned in the methodological part, the research was conducted among respondents who in total owned 16,907.95 hectares of agricultural land. The average area of the farms studied was 35.22 hectares. The majority of the respondents lived in individual family homes with a relatively large living area. Almost half of the respondents reported the living area of their residential properties to be above 150 m^2. From the point of view of the conducted considerations, the year of construction was very important, as this indirectly indicated the construction technology used at the time (hollow brick, brick, aerated concrete, silicate etc.), as well as the insulation technology and systems (polystyrene, glass wool etc.). Over 60% of the buildings used in the analyses were erected before the end of the 1980s (Table 1).

In the research survey, the respondents also answered questions relating to conducted and planned thermal upgrading, indicating their scope and time frame (amongst others in relation to planned action). The respondents answered the question: 'Has there been any thermal upgrading to the household or the farm, or is any such action planned?' The question was divided into several parts due to the subjective scope of the analyses. Respondents answered the questions relating to thermal upgrading with regard to: (a) insulation of external walls and ceilings, (b) window replacement, (c) door replacement, (d) replacement or modernization of heating systems. The results of this part of the research are presented in Tables 2 and 3.

The analysis shows that the majority of respondents declared that they had already conducted thermal upgrading in residential buildings, in particular with

Table 1 Main features of the residential properties studied. *Source*: Own study based on questionnaire surveys (N = 480)

Specification	Number of responses	Percentage in the research sample [%]
Type of development		
Free-standing	447	93.13
Terrace house	8	1.67
Semi-detached	9	1.88
Apartment	16	3.33
Usable area [m^2]		
Under 50	5	1.04
51–99	85	17.71
100–149	161	33.54
150–200	101	21.04
Over 200	128	26.67
Year of construction		
Earlier than the 1950s	89	18.54
1950s	24	5.00
1960s	47	9.79
1970s	71	14.79
1980s	98	20.42
1990s	59	12.29
2000–2009	45	9.38
After 2010	47	9.79
Total	*480*	*100*

regard to window replacement (79.2% of respondents). The lowest percentage of completed modernization to date was the replacement or modernization of heating systems (57.5% of respondents). The results regarding plans for thermal upgrading are interesting. The respondents could choose between two time periods for planned action (by 2025 and after 2025). Such intentions could also be indicated by respondents who had earlier reported that thermal upgrading had already been conducted. This related in particular to situations in which such modernization had been conducted a relatively long time ago, and/or the work carried out in this respect did not fulfil current expectations with regard to thermal comfort etc. The research showed that over 30% of respondents plan to replace or modernize heating systems (15.2% of respondents by 2025 and 16% after 2025). A considerable percentage also plan to insulate external walls and ceilings (in total 28.3% of respondents). Respondents' declarations regarding thermal upgrading in farm buildings and livestock rooms are presented in Table 3.

Prior thermal upgrading reported by respondents of buildings and farm buildings used for agricultural activity was not common. Only one in four respondents reported the replacement of windows and doors. Even less action had been taken in terms of insulating external walls and

Table 2 Conducted and planned action with regard to thermal upgrading of residential buildings [%]. *Source*: Own study based on questionnaire surveys (*N* = 480)

Details	Current status		Plans	
	Yes, conducted	Not conducted	Planned by 2025	Planned after 2025
Insulation of external walls and ceilings	65.6	34.4	15.0	13.3
Window replacement	79.2	20.8	6.9	11.5
Door replacement	72.9	27.1	11.3	11.0
Replacement or modernization of heating systems	57.5	42.5	15.2	16.0

Table 3 Conducted and planned thermal upgrading in buildings and farm buildings. *Source*: Own study based on questionnaire surveys (N = 480)

Details	Current status		Plans	
	Yes, conducted	Not conducted	Planned by 2025	Planned after 2025
Insulation of external walls and ceilings	12.3	87.7	6.9	19.6
Window replacement	25.2	74.8	9.8	17.7
Door replacement	26.0	74.0	10.0	16.9
Replacement or modernization of heating systems	6.9	93.1	3.1	20.4

ceilings (12.3% of respondents), and the replacement or modernization of heating systems (6.9% of respondents). However, the respondents declared a relatively high level of interest in such modernization, in particular the replacement or modernization of heating systems (which most intend to conduct after 2025—98 respondents). The study also showed that there will be significant interest in this time period in insulating external walls and ceilings.

The principal feature of the considerations proposed in this paper is the existence of a link between selected categories of factors influencing reported intentions with regard to thermal upgrading and the production and economic features of farms (area of agricultural land, economic size of a farm, agricultural production system, farm location). For this purpose, correspondence analysis was conducted, a specialized method for examining the co-occurrence of variables which allows for study of the dependencies between the studied factors. Among the indicated scope of modernization (Tables 3 and 4) "replacement or modernization of heating systems" was selected for the analyses, that is the scope of action most frequently indicated by respondents in the long term (after 2025).

In order to verify whether there are dependencies between the analysed features, a test of independence of nominal features was used based on the χ^2 statistic. Verification was conducted at a significance level of $\alpha = 0.01$. On the basis of the χ^2 statistic values, the strength of the dependencies between the variables was also determined using the mean square multidimensionality index ϕ^2 (Table 4).

The critical values read from the chi-square distribution tables, at a significance level of $\alpha = 0.01$, for all pairs of features are smaller than the calculated χ^2 statistics. This means that the hypothesis of the independence of the studied features should be rejected, wherein plans for replacement or modernization depend on the agricultural production system, the area of agricultural land, the economic size of a farm, and the location of a farm. Statistical analysis demonstrated the existence of strong dependencies between modernization or replacement plans and:

- the agricultural production system ($\phi^2 = 0.1503$),
- the economic size of a farm ($\phi^2 = 0.1100$),
- the district ($\phi^2 = 0.0947$).

The correspondence analysis also allowed us to determine these dependencies more precisely (Fig. 2).

The results of the correspondence analysis based on the Burt matrix showed that there is co-occurrence between the studied variables. Respondents who intended to replace or modernise the heating system in farm buildings by 2025 (E1) were characterised by a relatively small economic farm size (S1, S2), and a small area of agricultural farm land (U1). This may be linked to the relatively low cost of this work, and thus the possibility for this investment to be carried out sooner (using a farmer's own funds or external funds). People declaring modernization or replacement in the period E1 (to 2025) and E2 (after 2025) mainly conducted animal or mixed production (K2, K3).

Discussion

To sum up, the research showed that there is a high level of awareness among the residents of rural areas in terms of the importance and necessity of conducting thermal upgrading in residential and farm buildings under their ownership. The results prove that the scale of required investment is very large, especially in the most broadly represented group (the individual family homes segment). These results are in line with earlier findings in which the topic of thermal upgrading was a key issue in the development of the low-emission economy in rural areas in Poland [56].

It is also crucial to link the research results with other important elements of sustainable energy in rural areas. Completed and planned initiatives that aim to reduce energy use for heating buildings are important not only in terms of an increase in energy efficiency, but also

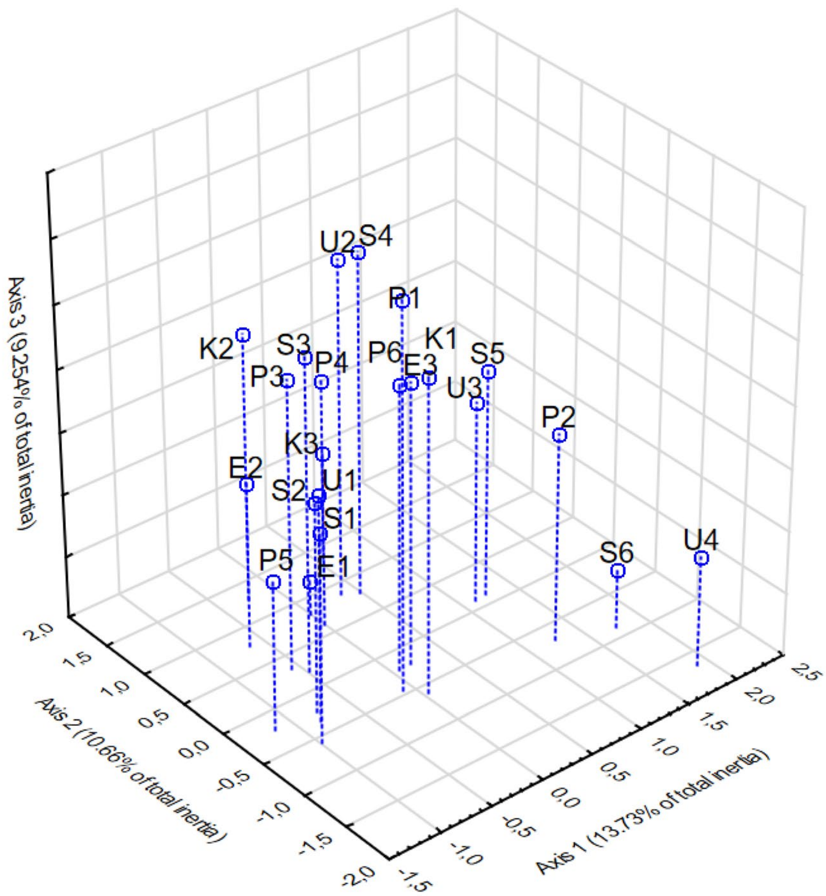
Table 4 Values of the χ^2 statistic, critical values χ^2 $\alpha = 001$* (in brackets), mean square multidimensionality φ^2 for features related to plans for the replacement or modernization of heating systems, agricultural production system, area of agricultural land, economic size of a farm and location (district). *Source*: own elaboration

χ^2 **φ^2**	**Agricultural production system** **$c^{***} = 3$**	**Area of agricultural land** **$c^{***} = 4$**	**Economic size of a farm** **$c^{***} = 6$**	**District** **$c^{***} = 6$**
Replacement or modernization of heating systems $r^{**} = 3$	*64.7909* *(13.2767)* 0.1503	*21.2890* *(16.8119)* 0.0494	*47.4040* *(23.2093)* 0.1100	*40.8211* *(23.2093)* 0.0947

[*] Critical values $\chi^2 \alpha = 0.01$ read from the tables for $(r-1) \times (c-1)$ degrees of freedom

[**] Number of rows of the variables analysed

[***] Number of columns of the variables analysed



Variable	Replacement or modernization of heating systems			Agricultural production system			Area of agricultural land [ha]				Economic size of a farm [SD]						District					
	Yes, by 2025	Yes, after 2025	No	Plant production	Animal production	Mixed production	5-19.99	20-49.99	50-99.99	100 and more	<10 thous. euro	10.1-13 thous. euro	13.1 - 20 thous. euro	20.1-50 thous. euro	50.1-100 thous. euro	>100 thous. euro	Dolnośląskie province	Zachodnio-pomorskie province	Lubelskie province	Warmińsko-mazurskie province	Małopolskie province	Łódzkie povince
Symbol	E1	E2	E3	K1	K2	K3	U1	U2	U3	U4	S1	S2	S3	S4	S5	S6	P1	P2	P3	P4	P5	P6

Fig. 2 Graphical presentation of correspondence analysis relating to plans for the modernization or replacement of heating systems in farm buildings, and selected production and economic features of farms. *Source*: Own study based on questionnaire surveys (*N* = 480)

from the perspective of reducing emissions. In Poland, solid fuel is used on a very wide scale for the production of electricity and heat. This applies not only to the professional energy sector, but also to individual heat sources in residential buildings [13]. According to data from the Central Office for Construction Supervision in Poland (GUNB) in the Central Building Emissions Register (CEEB), the majority of the heat sources reported are devices that use solid fuel (5.36 million out of 9.8 reported heat sources). In this category, the most numerous are solid fuel boilers (coal, wood, pellets or other biomass), of which there are nearly 3.4 million (2.2 million fed manually and 1.1 million with automatic fuel feed). In addition, over a million solid fuel fireplaces, stoves and air heaters are in use. On top of this there are 435,000 tile stoves in Poland and over 520,000 kitchen heating systems, kitchen stoves and coal kitchen stoves (https://samorzad.pap.pl/). Legislative and regulatory action taken over many decades has not stimulated the decarbonisation of the residential sector, and has also not taken into consideration problems such as energy poverty and air pollution [67, 73]. Technical and economic analysis of completed thermal upgrading of residential buildings has shown that there is a reduction in pollution of the air with particles and sulphur oxide, as well as savings in heat energy [35].

Currently, especially as a result of the adoption and respecting of solutions adopted in the European Union (simplified administrative procedures, development of national action plans taking into account the schedule for the growth in renewable energy), as well as an increase in awareness regarding protection of the natural environment in Poland, this topic is the subject of many political and scientific debates, as well as legislative initiatives, including the issue of subsidies. Thermal upgrading is usually very costly for the owners of houses and other buildings (such as in the considerations discussed, e.g., the insulation of livestock buildings—chicken coops, pigsties, buildings for poultry, cowsheds etc.). The high costs relate especially to residential buildings, for which the average cost of comprehensive thermal upgrading is estimated to be from 200 to 400 PLN for every 1 m^2 of living area. In the case of a 150 m^2 building, this amounts to 30,000 to 60,000 PLN (https://termomodernizacja.org/). Of course, these are very general calculations, and in every individual case the costs must be calculated by taking into account the result of the energy audit, the current prices of building materials, labour etc. Nevertheless, the high cost often means that it is necessary to seek external financing (credit, loans, subsidies).

Of key importance in this subject area are the possibilities for funding and support programmes for financing thermal upgrading, including in particular the national ‘Clean air’ programme (Clean Air Priority Program—CAPP), which was launched in September 2018 [44, 47]. The programme is aimed at owners and co-owners of individual houses or individual residential properties with a separate land and mortgage register located in blocks of flats. The subsidies for thermal upgrading of homes and replacement of heat sources were initially set at a maximum of 135,000 PLN (variant for people with a relatively low income). Financial subsidies can be obtained for:

- photovoltaic micro-installation,
- mechanical ventilation with heat recuperation,
- central heating and water heating installation,
- replacement of an old solid fuel boiler or stove (coal, wood) with a modern heat source,
- energy audit,
- insulation of walls, ceilings and floors,
- replacement of windows, doors and garage doors.

According to data as of 12.01.2024 (from 19.08.2018), a total of 761,927 applications have been submitted under the ‘Clean air’ programme, and 650,377 agreements have been signed (the total amount of subsidies from the agreements amounts to 17,302,418,665 PLN (https://czystepowietrze.gov.pl/). In 2022, a national programme was announced for the owners and co-owners of individual houses with old coal boilers. This was the ‘Clean air + ’ priority programme in which 1.8 billion PLN was allocated for thermal upgrading.

There are also other important programmes, including ones directed towards local authorities. These include, for example, the ‘Stop Smog’ programme, which is intended for districts located in areas where so-called anti-smog regulations are in force, supporting the removal or replacement of energy sources with low emission sources and thermal upgrading in individual residential buildings for the least well-off [21, 39]. The subsidies in this programme are provided by the Renovation and Thermal Upgrading Fund and amount to 70% of the costs detailed in the agreement. There is also the ’Warm living’ programme also intended for districts, who announce the programme in their area for physical persons in possession of a legal property title resulting from legal ownership or limited property right to a residential premises within a multi-premises building (the subsidy may be up to 39,900 PLN). The results of the first round of the ’Stop Smog’ programme were seven agreements to the value of 54 million PLN—of which 37.4 million PLN was from the state budget and around 17 million PLN from the districts themselves. The funds were used for investments in around 1,100 buildings. In the years 2022–2024, the Renovation and Thermal Upgrading Fund will receive around 518 million PLN for low-emission initiatives within the ’Stop Smog’ programme’.

From the 1st of January 2019, there are regulations in force in Poland on the basis of which a taxpayer who is an owner or co-owner of an individual residential building can apply for a thermal upgrading rebate. This rebate involves deducting from gross taxable income costs incurred for ‘thermal upgrading projects’ in an individual Residential Building up to and expense limit of 53,000 PLN (for all completed thermal upgrading projects) (https://czystepowietrze.gov.pl/).

There were also programmes and action aimed at farmers, in which funding could be obtained for ’thermal upgrading’. Amongst others, it was possible to obtain funding to cover part of the costs related to investments for thermal upgrading as part of the Rural Areas Development Programme in the years 2014–2020 (PROW 2014–2020) within the sub-programme 4.1 'Support for investments in farms'. Campaigns of the type 'Modernization of farms' as part of this sub-programme could be used, for example, to improve the efficiency of energy use in farms [34]. Taking into account the current financial perspective of 2021–2027, analysis of programme documents conducted by Wasilewski et al. [71] showed that the financing of investments such as thermal upgrading projects aimed at improving energy efficiency, would come from cohesion policy funds. This places into serious question the possibility for farmers to apply for such funds, especially those from peripheral areas. Nevertheless, legislative changes have been made in this respect, and according to the selection schedule, from the 25th of January 2024 it is possible to submit applications for subsidies for investments in renewable energy sources for the needs of farms. Nevertheless, this support should be suitably addressed, taking into account the real needs of farm owners (with consideration for the physical and economic size of a farm, the production specialization and the location).

European Union funds have played and continue to play a primary role in the development of renewable energy sources in Poland, including the context of the European Union's cohesion policy [8]. Considering the spatial scope of the analyses in this paper (rural areas), the literature emphasizes the need to strengthen education in the community and more generous, long-term institutional support from the central government. This support should be focused on endogenous development and strengthening of local social capital [9]. Support in the form of subsidies, tax relief or low-interest loans is necessary.

Since 13 September 2023, detailed guidelines have been in force regarding the granting, payment and reimbursement of aid for interventions I. 10.2. Investments in agricultural holdings in the field of RES and energy efficiency improvement under the Strategic Plan for the Common Agricultural Policy for 2023–2027 (https://www.gov.pl/web/rolnictwo/). The guidelines were issued on the basis of art. 6 paragraph 2 point 3 of the Act of 8 February 2023 on the Strategic Plan for the Common Agricultural Policy for 2023–2027. These guidelines refer to three areas of support specified in I.10.2 in the CAP PS, in which investments concern:

1) Area A—agricultural biogas plant;
2) Area B—micro-installations producing energy from solar radiation;
3) Area C—solutions improving the energy efficiency of farm buildings.

The analysis of the guidelines has highlighted several problems that may be significant in the implementation of the programme. First, the complexity of the procedures and the articulated conditions for implementation may prove significant. The process of applying for aid may be too complicated and time-consuming, which may discourage farmers from submitting applications. Moreover, the conditions for implementing the operation may be difficult to meet, which may lead to problems with payment (24 months—single-stage projects or 36 months from the date of conclusion of the agreement on granting aid). In addition, the criteria for selecting the operation may be difficult to meet for some farms, which may limit the availability of aid. On the other hand, one of the conditions for receiving aid (the applicant must have been producing livestock in the last 12 months preceding the month in which the application deadline begins) may be controversial from the point of view of maintaining the sustainability of the project. Another issue concerns the amount of aid. The maximum amount of aid (in the form of a refund of up to 65% of the eligible costs of the operation) may not be sufficient to cover all costs related to investments in RES and improving energy efficiency. This applies in particular to commercial farms in all aid areas (the maximum amount of aid is given in brackets):

- area A—1.5 million PLN;
- area B—200 thousand PLN;
- area C—200 thousand PLN.

The total aid limit per beneficiary was set at:

1) area A and area B—1.5 million PLN;
2) area A and area C—1.7 million PLN;
3) area B and area C—400 thousand PLN;
4) area A, area B and area C—1.7 million PLN.

Nevertheless, this is a good step towards the development of RES and increased energy efficiency in rural areas in Poland. Especially in the situation of unused potential in the production of biomass for energy purposes [17]. Despite the initial, dynamically developing agricultural biogas sector (from January 1, 2011 to January 1, 2017, 86 installations were created and entered in the register of agricultural biogas producers in Poland), the following years were not characterized by high growth dynamics. As of January 1, 2023, only 143 installations were operating in Poland, and the total biogas production in 2023 amounted to 428.406 million m^3. Considering the importance of this topic in the context of the construction of distributed energy, including in particular infrastructural deficiencies in rural areas in Poland, great hope is placed in the development of the agricultural biogas market. Agricultural biogas plants, as stable sources of renewable energy, can contribute to improving the quality of energy supplies in rural areas [11]. Moreover, it can be an important element in the circular economy model (using not only residues from agricultural production, but also from the food industry and trade—e.g., expired food) [12, 57].

Conclusion and future research

There is no doubt that thermal upgrading is both a significant challenge and an opportunity for rural areas in Poland. It is a challenge in particular in the context of the very large number of farms in Poland and the years in which residential buildings and farm buildings used in Polish agriculture were erected. Many buildings have high energy needs and require considerable thermal upgrading. Results of this research demonstrate the high level of awareness of the inhabitants of rural areas with regard to the need for thermal upgrading of buildings. This concerns both residential buildings and farm buildings. In many cases, residential buildings have already undergone thermal upgrading, however, very few such projects have been undertaken in production buildings (chicken coops, pigsties, cowsheds etc.).

In the above context, an interesting cognitive aspect is the use of MCA, which can be useful in areas such as these, where obtaining detailed information on the current modernization status is limited. The research shows that planned support with regards to possible financing of thermal upgrading projects should take into consideration the physical and economic size of a farm, the production system and the location.

Thermal upgrading of residential buildings ensures better living standards for residents, wherein economic and environmental issues are particularly important. Meanwhile, thermal upgrading of farm buildings improves animal welfare, contributing to better production results. Creating and maintaining a suitable microclimate within livestock buildings not only involves thermal upgrading, but also numerous engineering and technical challenges in the field of innovative, intelligent control and monitoring systems. The conclusions of the research, including the types of planned thermal upgrading projects and planned deadlines for their completion, can provide valuable information for building engineers and other interested parties, as well as identifying the most promising programmes and means. Introducing this topic into the public debate may contribute to a considerable increase in social awareness of the issue, as was seen in the field of residential buildings. There is, however, a need to develop research on the energy consumption side of the agricultural sector in Poland (living and production), including focusing on psychological and social models of energy consumption.

Accelerating the process of thermal upgrading in the Polish farming sector and in rural areas should be a priority of agricultural and social policy, especially in the current situation on energy markets. The costs of using electricity, especially for animal production, can be reduced by investing in renewable sources of energy and energy storage on farms, and by improving energy efficiency. This requires the creation of targeted programmes for farmers that take into account appropriate training, advisory and financial support. The basic factor differentiating the type of support should be the location of farms, which would allow for taking into account, among other things, local and regional air pollution caused by low emissions. However, inventory of the appropriate resources (e.g., in terms of biomass supply in the context of developing agricultural biogas plants) and creation of appropriate plans and programs seem to be necessary. It is also necessary to undertake appropriate action to communicate with recipients. Above all, this opens up a broad perspective for analyses in the field of the technical, economic and environmental efficiency of new installations/ heating devices, etc.

Abbreviations

CAPP	Clean Air Priority Program
CEEB	Central Building Emissions Register in Poland
EED	Energy Efficiency Directive
GUNB	Central Office for Construction Supervision in Poland
MCA	Multiple correspondence analysis
ODR	Agricultural Advisory Centres
PROW	Rural Development Plan
PSR	Agricultural census
RES	Renewable energy source

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Availability of data and materials
The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The Rector's Committee for Ethics of Scientific Research at the University of Economics in Wrocław, based on the application of the author of the work (research project manager), issued a positive opinion on ethical questions (Application No. 57/2020).

Consent for publication
Not applicable.

Competing interests
The author declares that no known competing financial interests or personal relationships could have appeared to influence the work reported in this paper.

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