

Article

Potential and Scenarios of Variants of Thermo-Modernization of Single-Family Houses: An Example of the Lubuskie Voivodeship

Maciej Dzikuć^{1,*}, Arkadiusz Piwowar², Szymon Szufa³, Janusz Adamczyk¹ and Maria Dzikuć¹

¹ Faculty of Economics and Management, University of Zielona Góra, Licealna Street 9, 65-417 Zielona Góra, Poland; J.Adamczyk@wez.uz.zgora.pl (J.A.); ma.dzikuc@wez.uz.zgora.pl (M.D.)

² Faculty of Economics and Finance, Wrocław University of Economics and Business, Komandorska Street 118/120, 53-345 Wrocław, Poland; arkadiusz.piwowar@ue.wroc.pl

³ Faculty of Process and Environmental Engineering, Lodz University of Technology, Wólczańska Street 213, 90-924 Łódź, Poland; szymon.szufa@p.lodz.pl

* Correspondence: m.dzikuc@wez.uz.zgora.pl

Abstract: The excessive air pollution in the Lubuskie Voivodeship and throughout Poland is a very serious problem. One of the main causes of poor air quality is low emission, which arises at a short distance from the ground (up to 40 m). The real reduction of low emission requires a series of measures. The most important of them, include replacement of non-ecological boilers heating single-family buildings, improvement of thermal insulation of outer building walls, development of public transport, limiting the movement of old, non-ecological cars, conducting extensive educational activities, economic support for the poorest families in pro-ecological activities, and development of district heating in urban areas. The issue of thermal modernization is also important from the point of view of ensuring an appropriate level of energy security in the social dimension. The article presents a scenario analysis of activities aimed at reducing low emission through economic support for thermal modernization of single-family houses in the Lubuskie Voivodeship in Poland. The results of the conducted research prove that it is possible to carry out thermal modernization of over 12% of all single-family buildings in the Lubuskie voivodeship, assuming that the co-financing would amount to 60% of the costs of such an investment. The analyses carried out in the article are closely related to low carbon development, and a significant part of emission of harmful substances into the air comes from heating single-family buildings in urban and rural areas.

Keywords: low carbon development; economy; energy; ecology; thermo-modernization



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1. Introduction

Air quality in Poland is one of the worst in the EU. Every year, high concentrations of suspended particulates (PM₁₀ and PM_{2.5}) and nitrogen dioxide (NO₂) are observed throughout almost the whole country. On the other hand, high concentrations in the air of substances such as benzo(a)pyrene—B(a)P from the group of polycyclic aromatic hydrocarbons (PAH) are particularly dangerous for human health [1–3], which are emitted mainly from individual building heating systems [4,5]. In 2015, the heating of buildings was responsible for 87% of the total PAH emissions and 80% of B(a)P emissions in Poland. It is sometimes mistakenly thought that PAH and B(a)P occur only in heavily industrialized areas and characterized by dense residential buildings (Figure 1).

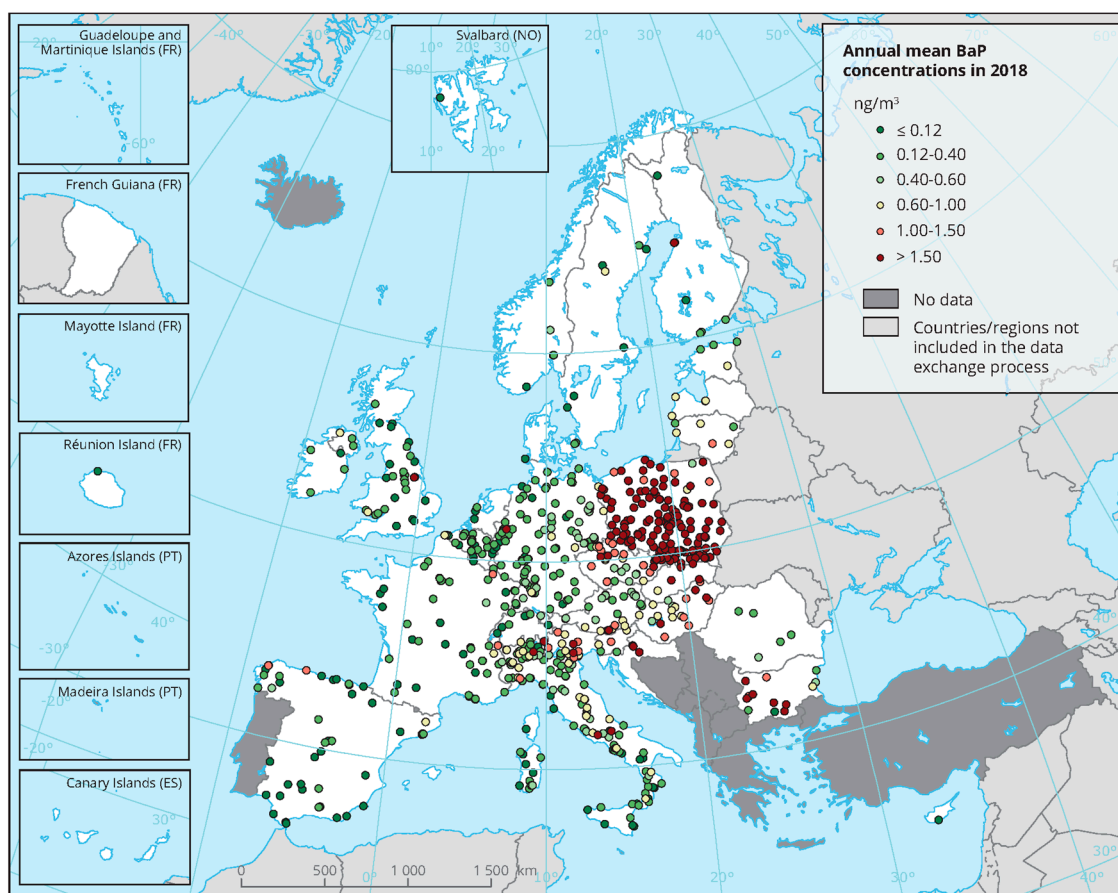


Figure 1. Concentrations of benzo(a)pyrene (BaP), 2018 [6].

However, these substances are found all over the country, where there are residential buildings heated individually. In 2016, the target level of B(a)P was exceeded in Poland at almost all points where measurements were carried out (122 out of 129 positions). In 2016, the average annual mean concentration of B(a)P for all measuring stations in urban and suburban areas was 5.20 ng/m^3 and was over five times higher than the target level. There were places in Poland where B(a)P pollution was particularly high. As much as 7% of measurement positions in urban and suburban areas were indicated by the average annual concentration, which exceeded the target level of B(a)P more than ten times. High concentrations of B(a)P in Poland are not of an individual character that occurred in one analyzed year. High concentrations of B(a)P have been present in Poland for years [7,8]. On the other hand, the highest values of the average concentration of B(a)P occurred in 2010 and 2012 and exceeded the target level about six times [9]. The article presents a scenario analysis of activities aimed at reducing low emission through economic support for thermal modernization of single-family houses in the Lubuskie Voivodeship. The analyses carried out in the article are closely related to low carbon development, and a significant part of emission of harmful substances into the air comes from heating single-family buildings in urban and rural areas. It is worth highlighting that the one of scenario proposed in the article could be a significant alternative on a regional scale to the "Clean Air" program. In Poland in September 2018 the Clean Air program was launched, which aims to reduce harmful emissions of gases and dust into the air.

2. The Impact of Emissions from Households on Air Quality

According to the data from the last National Census, almost 45% of the apartments were built before 1970. Almost 43.5% of the apartments were built in 1971–2002, therefore only less than 12% were built in 2003–2011. The number of flats in Poland in 2011 was

13.56 million [10]. However, the number of residential buildings was 5.54 million, of which as many as 5 million were single-family buildings [11]. In 2012–2016, less than 752 thousand flats were put into use in Poland, which means that their number has increased by approximately 5.5% since 2011. It should be emphasized that single-family housing dominates in Poland in rural areas, where 97% are single-family buildings, and 3% are multi-family buildings. In cities, on the other hand, 80% are single-family and 20% multi-family buildings. It is difficult to precisely determine how much the age structure of residential buildings has changed, because some of the old houses ceased to exist or are not currently inhabited. However, based on the above data, the assumption can be made that since the National Census was carried out in 2011, the structure of the number of apartments according to the construction year has not changed significantly [12].

The best ecological effect in relation to the expenditures is provided by the replacement of an old boiler, e.g., coal-fired, used to heat the building [13–15], for a modern boiler, e.g., fired with natural gas [16,17]. However, this is not an activity that clearly contributes to reducing the costs associated with heating the building [18,19]. It is hardly surprising for the less affluent inhabitants that they do not always willingly reach for the financial means offered by the local authorities for the replacement of the boiler [20]. This is even the case with 100% coverage of boiler replacement costs. In the case of replacement of the old type boiler, which is fired with solid fuel for a modern boiler fired with natural gas, it is assumed that the costs related to heating the building will be increased [21–23]. Only the insulation of the outer building walls, along with the replacement of window and door joinery can give a noticeable economic effect. However, comprehensive thermal modernization is much more expensive than the operation consisting only in exchanging the boiler [24].

The structure of energy consumption in households in recent years has not changed significantly. Surprisingly, however, the share of energy consumption for heating purposes decreased from 71.3% in 2002 to 65.1% in 2018 and still has the largest share in the total energy consumption of households (Table 1). In the years 2002–2012, the share of energy consumption related to lighting decreased, which was mainly caused by the wider use of energy-efficient lighting. On the other hand, the energy consumption related to the use of electronic equipment was systematically increasing, which was mainly caused by the greater availability of this equipment, associated with relatively low prices and the growing interest of Poles in various types of electronic equipment [25–27].

Table 1. Structure of energy consumption in households by end use [28].

Items	2002	2009	2012	2015	2016	2017	2018
	%						
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Heating	71.3	70.2	68.8	65.5	66.2	65.8	65.1
Water heating	15.0	14.4	14.8	16.2	16.0	16.3	16.6
Cooking	7.1	8.2	8.3	8.5	8.3	8.3	8.5
Lighting	2.3	1.8	1.5	9.8 (*)	9.5 (*)	9.6 (*)	9.8 (*)
Electrical equipment	4.3	5.4	6.6				

(*) jointly lighting and electrical equipment.

It is worth noticing that heating of buildings has the largest share in total energy consumption by households, and at the same time contributes the most to low emission [29,30]. This is because the fuels burned for heating buildings are often burnt in energy-inefficient boilers, which are additionally fuelled by low quality, contaminated fuel [31]. This is confirmed by the data contained in Table 2. Over 80% of Poles in their households for space heating in recent years used coal or wood [32–35], and this state of affairs was maintained in 2002–2015. Being aware that a large proportion of boilers was fired with solid fuels in old type boilers that do not meet current ecological standards. Biocoal from biomass

torrefaction process is a fuel, high-energy renewable fuel (up to 27 MJ/kg), for use in the supply of efficient systems for the production of energy from renewable sources and in individual consumption. Biocoal is characterized by lower content of volatiles, high carbon content and is the cleanest organic fuel on the market (characterized by, among others, low chlorine and sulphur content, below 0.05%). It provides stable high temperature for long periods of combustion (over 50 min). It does not generate too much of particulates during combustion (responsible for smog). Its application will respond to market needs related to the search for renewable fuel, reduction of greenhouse gas, and dust emissions [36–42]. It is also worth mentioning that some buildings are equipped with two heating installations, e.g., a wood fireplace and a natural gas boiler [43–45].

Table 2. The share of households using energy sources for space heating for the years 2002, 2009, 2015, and 2018 * [46].

Source of Energy for Space Heating	2002	2009	2012	2015	2018
	%				
Electricity	3.7	6.9	5.4	4.5	2.6
Heat from the heating network	43.3	40.2	41.5	41.7	40.3
Natural gas **	6.6	9.2	8.8	10.1	14.0
Liquid gas (propane-butane)	0.1	0.4	0.3	0.3	0.5
Heating oil	0.4	0.5	0.4	0.4	0.5
Coal	40.9	42.7	40.8	40.4	36.5
Lignite	no data	1.2	1.4	1.1	0.5
Coke	3.5	0.8	0.7	0.8	0.6
Firewood	38.2	42.5	40.0	41.7	28.8
Other types of biomass	2.1	6.2	4.3	3.0	1.3
Solar energy	no data	0.04	0.07	0.15	0.13
Heat pump	no data	0.03	0.05	0.07	0.28

* The sizes of energy carriers' consumption are given per household actually consuming the energy carrier; ** Data for 2002, 2009, and 2012 are only for high-methane gas.

3. Determination of the Number of Buildings that Could Be Subjected to Thermo-Modernization

The research was carried out in the Lubuskie Voivodeship. The aim of such a solution was to take into consideration the area that is separated statistically. Different types of reports are carried out for the Lubuskie Voivodeship, which, among other things, relate to the issues raised in this article. The research was carried out from July to September 2020. The study was conducted on a sample that was able to generalize the results from the sample to the entire study population with a relatively low probability of making a mistake. Over one million people live in the Lubuskie Voivodeship, of which about half in single-family buildings. Due to the size of the sample, it was necessary to determine the minimum number of respondents. In order to determine the minimum representative size of the sample, the following formula was used [47]:

$$n \geq \frac{1}{4} \left(\frac{u_{\frac{\alpha}{2}}}{d} \right)^2 \quad (1)$$

where

n —minimum representative size of the sample

u —critical value of the normal distribution

d —statistical error

$\alpha = 0.05$

$$d = 0.05$$

$$u_g = 1.9599$$

Hence,

$$n \geq 384.12$$

After substituting the formula, the number of observations should not be less than 385. The assumption has been made that the structure index will be estimated at the confidence level of 0.95 ($\alpha = 0.05$). Statistical error 5% ($d = 0.05$). However, 400 adult people living in single-family houses in the Lubuskie Voivodeship took part in the research.

Respondents, who were people living in single-family houses in the Lubuskie Voivodeship, were asked about plans to carry out thermo-modernization of their home within the next three years, most often they answered negatively (51% of responses). Most of the inhabitants of the Lubuskie Voivodeship gave a negative answer without indicating a reason. A little over 11% of respondents do not plan this type of investment, because they consider their apartment to be well insulated, and 2.75% do not intend to carry out thermal modernization of the house, even if it is possible to obtain funding for this purpose. On the other hand, 24.75% of respondents living in single-family houses in the Lubuskie Voivodeship plan to carry out thermo-modernization of their home within the next three years, the majority of them expressing readiness to carry out this type of investment only if they receive co-financing (Figure 2).

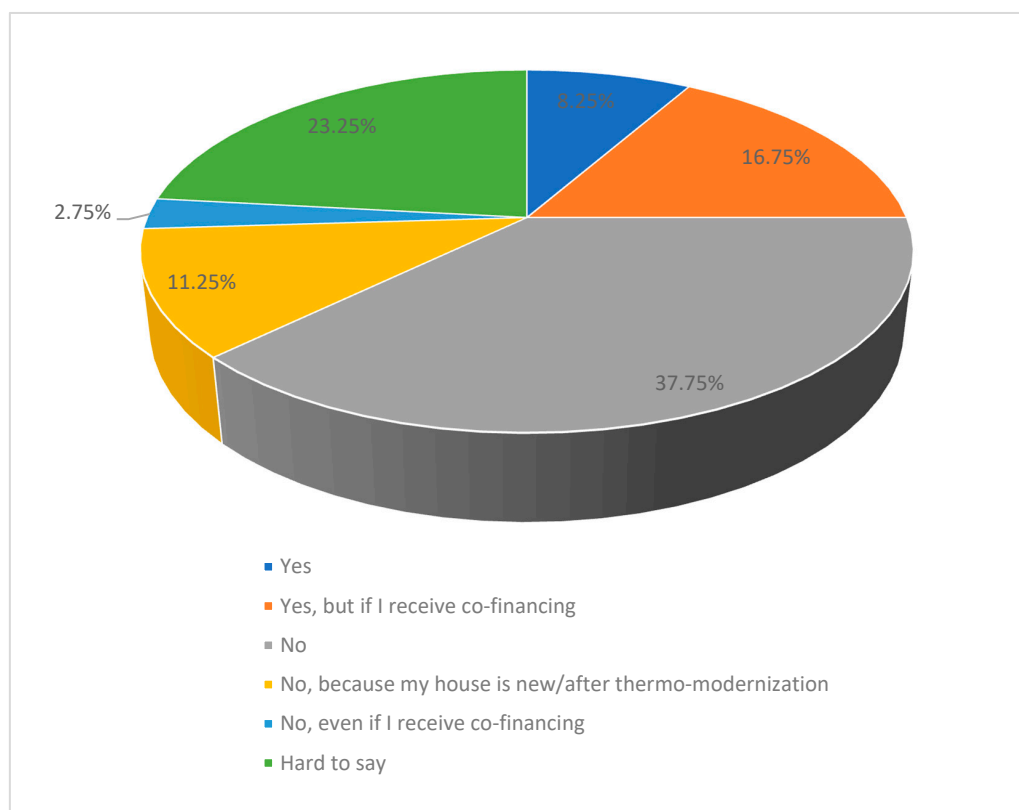


Figure 2. Respondents' answers to the question: do you intend to carry out thermo-modernization of your single-family home in the next 3 years?

4. Analysis of Thermo-Modernization Investment Scenarios in the Lubuskie Voivodeship

According to the data obtained during the National Population and Housing Census in 2011 and the assumption that the share of single-family buildings in the country was similar also in the Lubuskie Voivodeship, it needs to be taken that in the area where the research was conducted there were 145 thousand of single-family homes [48]. Assuming

that since the National Population and Housing Census in 2011, the number of these buildings has not changed significantly and 24.75% of people living in single-family houses will want to thermo-modernize their homes (according to the results of research), it is expected that 35,844 single-family houses could be thermo-modernized within the next three years. Assuming that the average cost of thermo-modernization can amount to about 15,000 euro, four different co-financing scenarios were adopted. The assumptions contained during the research result from extensive surveys conducted in the analyzed area and from the experience of the authors of the article who evaluate applications for co-financing of innovative and investment projects for various institutions (including the European Commission, Regional Operational Program, National Center for Research and Development). For many years, the authors of the article have been experts evaluating applications for co-financing projects implementing solutions improving environmental efficiency and reducing emissions of greenhouse gases and other harmful substances to the air. One of this kind of actions are programs on national level from Ministry of Climate and Environment programs for the modernization of distributed energy sources powered by fossil fuels [49]. Each scenario assumes a different number of people who decide to carry out thermo-modernization of their single-family building. The higher the co-financing amount, the more people will decide to carry out thermo-modernization. On the basis of interviews with respondents, the assumptions were made that

- with 100% co-financing all owners of single-family buildings will carry out thermo-modernization works;
- with 80% co-financing, 75% of owners of single-family houses will carry out thermo-modernization works;
- with 60% co-financing, 50% of single-family house owners will carry out thermo-modernization works;
- with 40% co-financing, 25% of single-family house owners will carry out thermo-modernization works.

Decisions made by the inhabitants of the Lubuskie Voivodeship regarding undertaking thermal modernization of single-family houses are conditioned mainly by economic considerations. The possibility of obtaining a high co-financing increases the probability of thermal modernization. It is worth emphasizing that when analyzing individual scenarios, not only ecological issues should be taken into consideration, which point to the urgent need to carry out such investments. While considering the most likely variant, the economic opportunities of local government authorities should be taken into account and the amount of funds allocated to similar activities should be taken into consideration. Such procedures make the probability of efficient implementation of the chosen variant more realistic. During the possible implementation of one of the selected scenarios, it will be necessary to observe whether the inhabitants behave in accordance with their previous declarations.

One of the financial options offered by the Lubuskie local government, which consists in supporting similar projects is the third priority axis: Low-Emission Economy, whose budget for 2014–2020 is slightly above 108 million euro. The project is financed from the European Regional Development Fund. Under this priority axis, beneficiaries in the EU budget perspective 2014–2020 may receive co-financing amounting to 85% of the planned investment, consisting in:

- increasing the share of RES energy production in the Lubuskie Voivodeship,
- increasing energy efficiency of buildings in the public and residential sector,
- reducing low emission pollution from the transport sector and reducing the outflow of passengers in public transport,
- reducing low emissions in cities,
- increasing the share of energy generated in cogeneration [50].

The beneficiaries of the indicated priority axis were mainly institutions and entrepreneurs from the Lubuskie Voivodeship. It is worth mentioning that the indicated

beneficiaries are usually located in cities. This means that the majority of projects will be implemented in urban areas, which will result in the inhabitants of rural areas and suburbs where there is a large number of single-family buildings will be less affected by the implementation of the Low-Emission Economy priority axis [51,52].

Analyzing the scenarios presented in Table 3, it should be stated that scenarios I and II could prove difficult to implement from an economic point of view. Without deciding how the funds would be transferred to persons carrying out thermo-modernization of their single-family houses, one should take into account the existing possibilities for financing investments in the region [53,54]. In order to determine the financial potential of the region in terms of financial support for thermal modernization of single-family buildings, reference should be made to the budget of the Regional Operational Program of Lubuskie 2014–2020. Due to the fact that the entire budget of this program for the period 2014–2020 is 906.1 million euro, it should be noted that scenarios I and II are currently not viable for economic reasons. Scenarios III and IV remain. Scenario IV assumes thermo-modernization of slightly more than 6% of all single-family buildings in the Lubuskie Voivodeship with costs that should not constitute too high a financial burden for the budget of the Lubuskie Voivodeship. However, scenario IV carries with it two serious threats:

- only sixteen single-family houses in the region would be thermo-modernized, and this is not enough to speak a significant ecological effect;
- with the co-financing of 40% of the costs related to the thermo-modernization, a large part of people initially interested in this investment could ultimately not decide on it because the amount they would have to spend on their own savings would be too high to accept.

Table 3. The number of single-family buildings subjected to thermo-modernization and the amount of co-financing for scenarios I–IV.

Scenario I	The grant amount per each family house at 100% financing (in thous. EUR)	15
	Number of single-family houses subjected to thermo-modernization	35,844
	The value of co-financing (EUR million)	537.66
Scenario II	The grant amount per each family house at 80% financing (in thous. EUR)	12
	Number of single-family houses subjected to thermo-modernization	26,883
	The value of co-financing (EUR million)	322.596
Scenario III	The grant amount per each family house at 60% financing (in thous. EUR)	9
	Number of single-family houses subjected to thermo-modernization	17,922
	The value of co-financing (EUR million)	161.298
Scenario IV	The grant amount per each family house at 40% financing (in thous. EUR)	6
	Number of single-family houses subjected to thermo-modernization	8961
	The value of co-financing (EUR million)	53.766

Source: own research.

The assumption should be made that scenario III would be the most optimal. Assuming a scenario that is closest to the amount earmarked for the implementation of the Low Emission Economy priority axis would be selected, it would be appropriate to indicate scenario III, which accepts a 60% co-financing of thermo-modernization measures. Moreover, accepting that owners of single-family houses, in accordance with their declarations, would actually benefit from this co-financing option, it would be possible to carry out thermo-modernization of over 12.36% of all single-family buildings in the Lubuskie Voivodeship. However, taking into account the experience of the local government authorities of the city of Krakow, which offered residents the possibility of receiving 100% of the costs related to replacing a non-ecological boiler with a greener one, it should be expected that not all residents who declared their thermo-modernization wish to actually carry it out. In Krakow, despite the possibility of receiving funding in the amount of 100% of costs related to the replacement of a non-ecological boiler, some residents did not decide to carry

out an investment. The inhabitants of the city of Krakow had various reasons to refrain from receiving a subsidy to replace the boiler. Some of these reasons may also occur in the Lubuskie Voivodeship, including unregulated issues related to property rights to real estate. However, there were also reasons indicated by the residents of the city of Krakow, which should not occur in the Lubuskie Voivodeship. These were the reasons related to economic issues. Parts of Krakow residents would not be able to afford heating a flat with a boiler that is more ecological and more energy-efficient, but is fired with more expensive fuel. Considering the fact that the boilers themselves were subsidized, even considering their higher efficiency, they could contribute to the increase of the heating costs of the building. This was because in the buildings only the replacement of boilers was subsidized, and the thermal insulation of the external walls was not improved. In the Lubuskie Voivodeship, when implementing the above-mentioned assumptions such concerns should not occur because, together with comprehensive thermo-modernisation, the costs related to heating single-family houses will be significantly reduced. These costs can fall by as much as 50 to 60% compared to the current expenses related to heating buildings.

Currently (December 2020), the demand for thermal energy in single-family houses may not exceed an average of 95 kWh/m²/year. However, from the beginning of 2021, these requirements will be tightened and it will be 70 kWh/m²/year. On the other hand, the buildings analyzed in the article in terms of thermal modernization, were usually built in the 1970s, 1980s, and 1990s. As a result of the analysis of the demand for thermal energy with the use of the CERTO computer program in single-family houses, this demand often exceeded 300 kWh/m²/year. The difference between the current legal requirements in terms of energy demand and the energy demand of buildings constructed in previous years has become the basis for finding an answer to the question of the profitability of a thermal modernization investment. The article also sought answers to the ecological optimization of the selection of a heat source.

5. Discussion

It needs to be mentioned that in Poland in September 2018 the Clean Air program was launched, which aims to reduce harmful emissions of gases and dust into the air. The Clean Air program provides for grants and loans, thanks to which investments will be implemented by owners of single-family buildings that will contribute to reducing the emission of harmful substances into the air. The Clean Air program assumes not only the reduction of gas and dust emissions arising during heating of existing residential buildings, but also aims to reduce air emissions from newly built residential buildings. The implementation of the Clean Air program is to last until 2029. However, the implementation of the program has not yet led to a noticeable reduction in emissions of harmful substances into the air, because during the first year of its operation only 1% of the assumptions of the Clean Air program were achieved. It is worth highlighting that the III scenario proposed in the article could be a significant alternative on a regional scale to the Clean Air program. The implementation of the III scenario, first in the Lubuskie Voivodeship, and in the case of success in the whole country, would be an important complement to a wide range of activities that are necessary to reduce excessive emissions of air pollutants. However, to increase the effectiveness of the implementation of the measures proposed in the III scenario, it is advisable to consider introducing a system of orders that will oblige owners of single-family buildings to carry out thermo-modernization of non-ecological apartment buildings. These activities are consistent with the assumptions of low carbon development, which is particularly important in a country such as Poland, whose energy is approximately 80% based on coal, and a large number of buildings have not been thermo-modernized. Moreover, a significant proportion of single-family homes are heated with energy-inefficient boilers, which are often fired with low-quality solid fuels. Thermo-modernization investments increase the energy efficiency of households. Investments in the field of thermal modernization of buildings are important from the point of view of counteracting and reducing energy poverty.

6. Conclusions

Poland has one of the most burdensome heating systems in Europe, which is mainly powered by hard coal. In addition, in the Lubuskie Voivodeship, compared to the provinces of Central and Eastern Poland, there is a much higher percentage of old buildings, built even before 1945, which are particularly energy-intensive. Subjecting some of these buildings to thermo-modernization may result in a significant reduction of low emission. The number of single-family buildings that can be thermo-modernized is strictly dependent on the amount of financial resources allocated for this purpose. Being aware of the limited financial resources available to the authorities of the Lubuskie Voivodeship and on the basis of the surveys carried out, a scenario allowing thermal modernization of approximately 10% of single-family houses in the Lubuskie Voivodeship was presented, taking into account the fact that not all persons pre-declaring willingness to carry out thermo-modernization of their single-family houses will actually do it. It is worth emphasizing that the amount planned to finance the proposed scenario in the light of the conducted analyses is real from an economic point of view and takes into account the current financial possibilities of the Lubuskie local government. The reduction of low emission generated during the heating of single-family houses is consistent with EU policy objectives, which is an additional argument that can be taken into consideration when analyzing measures to reduce low emission in the Lubuskie Voivodeship.

The implementation of thermal modernization works recommended in the article would help to reduce excessive concentrations of harmful substances in the air, e.g., suspended dusts PM10 and PM2.5 and B(a)P contained therein. It should be emphasized that a significant part of the emissions of the indicated pollutants into the air arises during the combustion of solid fuels in winter. Heating of single-family buildings in Poland with the use of low-quality fuels, which are additionally burned in energy-inefficient boilers, is one of the main reasons for exceeding the concentrations of harmful substances such as B(a)P in the air. Moreover, thermal modernization of buildings in Poland is also important from the point of view of reducing energy poverty. Thus, the issues described in the article are interesting both from the point of view of environmental protection and shaping the broadly understood quality of life.

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