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The Economic Effects of New Patterns of Energy Efficiency and Heat Sources in Rural Single-Family Houses in Poland

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Abstract: In the face of severe air pollution and implementation of energy and climate policy, it remains a challenge to develop effective strategies addressing the problem of solid fuels use in single-family houses (SFH) in rural areas in Poland. This study investigated the correlations between thermal modernization of SFH, the changes of heat sources from coal to clean energy, including heat pumps driven by prosumers' photovoltaic (PV) installation, and the disposable income of households in Polish rural areas. It also provided an analysis of the current support mechanisms promoting energy efficiency and PV development. The application of simulation modelling of energy consumption and costs in the research has proved that comprehensive thermal modernization of rural SFH constructed in the period of 1945–1970 and investments supporting PV/heat pump systems would enable the most cost-effective way of heating to be implemented. Considering that, today, spending on energy for heat puts a burden on the budget of rural households, especially those living in the SFH aged 50 years and more that dominate rural areas in Poland, the changes in energy supply–demand patterns would be an enhancement of their economic, energy and environmental security. The research argued that, in the wider process of energy transformation and solving air pollution problems, the role of rural households should not be neglected in public policy.

Keywords: rural areas; energy efficiency; photovoltaic systems; energy security; support mechanisms; public policy; energy policy; prosumer energy; single-family houses

1. Introduction

Energy efficiency and development of renewable energy sources have been identified as key areas of actions aimed at mitigating climate change. A need to improve energy efficiency has been highlighted by many international bodies, including the Intergovernmental Panel on Climate Changes (IPCC), United Nations (UN), and European Union (EU) [1,2]. In this context, the role of the residential buildings has been growing in importance across the EU. The residential sector, or households, constituted 26.1% of the EU's final energy consumption in 2018 [3]. Although the EU as a whole improved energy efficiency in this sector by around 29% (2.1%/year) over the period 2000–2017 [4], considerable differences in energy efficiency between the individual countries and regions were established. In many studies, introduced political measures, financial incentives and energy performance standards have been found a key factor in successful promotion of energy efficiency in the residential sector of individual EU countries [5,6]. Given the huge variations between the

Member States in both adapted policy measures and the existing energy efficiency potential in urban and rural areas, a case study-based approach of improving bottom-up data as well as understanding of the individual countries' needs and specificity has been postulated [5,7,8]

In terms of energy efficiency progress in household sector over the period 2008–2017, Poland was ranked 21st among the EU. With 1.13%/year rate of energy efficiency improvements, Polish households were below the EU's average and far below the improvements rate achieved by Poland's industry. Their role in meeting energy efficiency target and pursuing wider energy transformation can be substantial not only due to 28% share in final energy consumption [9] but also the fact that the most commonly used energy carrier in Polish households is coal. At the same time, there are considerable differences between urban and rural areas in Poland regarding income structure, the main source of heat, buildings' quality and their respective thermal modernisation needs and levels of pollution. Single-family houses aged 50 years and more are the vast majority of buildings located in Polish rural areas. Most of them are characterized by poor thermal insulation performance and the use of traditional fuels—coal and biomass—for heating. For this reason, they are a major source of air pollution in rural areas.

The scientific interest in energy efficiency and renewable energy development in rural areas in Poland has been growing. Studies on sectoral polices and potential for development of individual RES have been popular among Polish researchers [10–12]. They have often emphasized the importance of development of renewable energy production in rural areas based on local sources. Thus the role of biomass in both the context of sustainable development, achieving energy security (including greater self-sufficiency) and providing an alternative source of income for rural communities has been highlighted [10,13–15]. Problem of technologically obsolete heat sources used by Polish rural households has been analysed from the different perspectives. One of them is air pollution and ecological soundness perspective. Authors have focused on the emissions of atmospheric pollutants generated from heat sources in rural areas and displayed an environmental effect of the replacement of old heat sources [15,16]. The low use of renewable energy sources (RES) for energy purposes in rural areas has been presented as a reason for exceeding the air pollution standards [16], threatening not only environmental but also health security. Thus, air pollution as a result of the contemporary structure of energy for heat use in rural households has been discussed in a wider context of sustainable development and social security issues. Problems related to old and energy-intensive rural residential buildings and the domination of ineffective solid fuels and heat equipment used by rural households have been also analysed in relation to economic disparities between the urban and rural areas. In this approach, authors have concentrated on the energy poverty of rural households, indicating the need to broaden knowledge of rural communities on energy savings, develop RES and improve energy efficiency [17–19]. From a political and administrative perspective, there is a common view that both the development of local RES as well as the reduction of energy use per rural household requires changes in regulations, better support systems as well as environmental education among residents of rural areas [12,16,20,21].

So far, Poland's energy and climate security policy has been focused largely on the changes in the centralized large-scale energy system. Recently, the interest has been shifted to the role of households in the process of improving energy efficiency and transition from fossil fuels to renewable energy sources (RES). In terms of both economic and energy security, the rural areas present worse indexes than the urban ones. Among others, they depend more on solid fuels for heat, use more unit of energy per 1 inhabitant, and pay higher bills for electricity [22]. Nevertheless, there is a gap in scientific studies regarding exploration of how the economic situation, including an analysis of how the disposable income of a Polish rural household would be affected by the improvements in energy efficiency and changes to zero-emission sources. In this research, the main focus has been put on rural households due to the substantial income disparities between urban and rural areas, respectively, higher energy poverty and the fact that old single-family houses (SFH) dominate among the residential buildings in rural areas in Poland. Today, spending on energy for heat in 50-year-old (or older) SFH puts a burden on disposable income of rural households. As a result, their economic and energy security largely depends on the ability to change the present patterns of energy for heat supply and demand. Thus, it is important to fill the identified literature gap and address the question of links between improvements in heat consumption/production and an economic situation of rural households in Poland.

The aim of this article is to find the correlations between energy efficiency improvements of single-family buildings, the change of heat source from coal boilers to more environmentally sound sources, including zero-emission ones, and the disposable income and expenditure of rural households. In order to meet the energy and ecological security needs of rural areas, a special focus has been put on the economic analysis of a combined effect of comprehensive thermal modernization and installation of heat pump driven by prosumers' PV system. We attempt to find how the heating costs of rural SFH are affected by thermal modernization and change of heat source and if this translates to any considerable changes in disposable income of rural households. The study focuses on the most common type of rural residential buildings, i.e., single-family houses (SFH) and specifies the following tasks: (1) assessment of energy efficiency of SFH in rural areas and their thermal modernization potential; (2) assessment of heating costs with the use of different heat sources; (3) assessment of heating costs with the use of heat pump driven by PV prosumer installation (under Prosumer public support mechanism); (4) estimation of disposable income of rural households; (5) estimation of heating costs reduction impact on disposable income; (6) analysis of support mechanisms regarding energy efficiency and PV installations dedicated to rural areas.

Improvements in energy efficiency of SFH are perceived as one of the basic methods in enhancing energy security in terms of both availability and affordability of energy for heat. In this research, we focus on an affordability side of a household energy security, i.e., the heating costs and estimated financial savings as an effect of the changes in energy efficiency and heat source patterns in rural SFH. Thermal modernization, exchange of heat sources and development of PV installations, are three potential areas of actions, which shall improve an energy balance and economic situation in rural areas. To verify these links, the research deals with official statistical data for the single-family houses, final energy consumption and income structure in Polish rural areas and elaborates a simplified model for assessment of the energy demand for space heating in the SFH built in different periods. Correlations are searched between the age of the SFH building, its usable area and the final energy consumption.

In international studies, issues of improving energy efficiency in the SFH sector are widely discussed and presented from different perspectives. From a technical perspective, studies often focus on barriers of SFH thermal modernization (e.g., studies on Nordic countries [23,24]) Others concentrate on the impact of the renovation of SFH on energy consumption and other patterns like indoor climate [25], indoor air quality or thermal comfort [26]. Recent studies discuss many innovative clean energy technologies [27], which could be used in renovation of residential houses in order to improve their energy efficiency. Research on the use of different systems based on renewable energy, including the experimental investigations on heat pumps driven by PV systems in SFH have been rising in importance and popularity [28,29]. Such studies regarding SFH in Poland's climatic conditions show the applications of this renewable energy technology after thermal modernization of SFH can be cost effective and recommended [28]. The heat pump–PV system has been also considered one of solutions for rural SFH in this study. Taking the economic approach, researches focus on the financial processes of investments [30] and the cost effectiveness of SFH renovations, including renovating to Passive House level [31]. In this study, we focus solely on the reduction of heating costs (i.e., not the investments costs) after thermal modernization and change of heat source in model SFH in rural areas in Poland, and estimate its impact on the disposable income of a household. From the sustainable development perspective, some empirical studies show how high energy efficient cities may influence and guide energy efficiency in surrounding areas [32]. Interestingly, across the scientific disciplines, studies prove the need of public policy support in encouraging investments in energy efficiency especially in poorer regions [33,34]. In Poland, the scale of the investments in the area of thermal modernization of single-family buildings and fighting low emission also strongly requires dedicated public aid programs which can be financed both from EU and domestic funds. Such investments contribute to the realization of the EU objectives to fight climate changes enhanced by the European Green Deal announced in 2019 [35]. However, some public support measures ("Clean Air Program" in particular) have been controversial, since they encourage rural households to exchange old coal boilers to new more efficient ones instead of stimulating the change to zero-emission sources. Therefore, the theoretical deliberations and economic calculations discussed in this article have been compiled with analysis of existing support schemes.

2. Research Process and Methods

For the purpose of this study, the focus has been put on the residential buildings dominating rural areas in Poland, i.e., single-family houses (SFH). In order to estimate energy and financial savings for rural household resulting from the improvements in the thermal modernization of SFH and changes of heat sources from coal boilers to gas, electricity, heat pump/PV installations, the research process has been divided into the following steps.

During the first phase of the research process, on the basis of available data on the age structure of rural residential buildings and calculations of their final energy consumption [kWh/m^2/year], the two models of semi-family buildings for rural areas were defined (see Table 1). Secondly, energy and cost reduction coming from thermo-modernization of model SFH buildings and/or the change of heat source with special regard to PV/heat pump system was estimated. In this simulation energy savings were estimated first at the micro-level, i.e., of individual rural household, and later at the country level. In order to assess the nationwide potential and feasibility in improving energy efficiency and formulate recommendations, at the final stage of research it was important to review current support mechanism and discuss prospects for comprehensive thermal modernization and development of prosumers' PV in SFH in rural areas in Poland. At the final stage of the research process, we analysed the results.

In the simulation of energy and cost savings, certain assumptions were made regarding the characteristics of SFH buildings, the used thermal-modernization and heat technologies. Firstly, a comprehensive thermal modernization involves investments in windows and modernization and optimization of heating system as specified in Table 1.

Secondly, in methodology of costs estimations the following assumptions were made for the two model SFH buildings:

- Number of floors, 2;
- Geometric, 330 m^3;
- Heating space, 130 m^2;
- Usable area, 136.7 m^2.

Two variants after thermal-modernization were applied: (a) The central heating system will not change—efficiency of the heating system is 50%; (b) Replacement of the heat source with one of the following sources:

- 5th generation boiler—efficiency of the central heating system amounts to 80%;
- Installation powered by natural gas—efficiency of the central heating system amounts to 90%;
- Heat pump installation. The COP index was assumed to be 2.

Table 1. Model single-family houses (SFH) configuration parameters.

SFH	Before Modernization	After Thermal Modernization
construction of external walls	29 cm thick brick wall, air gap, facade brick. Heat transfer coefficient U = 0.65 [W/(m^{2}K)]. The area of external walls is 201 m^2	Thermal insulation of external walls (area of 201 m^2) with 20 cm thick mineral wool with a thermal conductivity coefficient of lambda = 0.036 W/(m^{2}K). Heat transfer coefficient of external walls U = 0.15 [W/(m^{2}K)]
roof	86 m2 roof area. Heat transfer coefficient U = 0.6 [W/(m^{2}K)]	86 m^2 roof area. Thermal insulation of external walls with 20 cm thick mineral wool with a thermal conductivity coefficient of lambda = 0.036 W/(m^{2}K). Roof heat transfer coefficient U = 0.14 [W/(m^{2}K)]
floor	86 m2. Heat transfer coefficient U = 0.6 [W/(m^{2}K)]	86 m^2. Floor insulation with 15 cm thick mineral wool with a thermal conductivity coefficient of lambda = 0.036 W/(m^{2}K). The floor's heat transfer coefficient is U = 0.2 W/(m^{2}K).
windows	total area of windows in the external walls: 21.3 m^2. Four windows, 1.435 m × 1.635 m each, on the southern and northern elevations. Two windows with dimensions 1.135 m × 0.565 m on the E and W elevations. The heat transfer coefficient U = 2.6 W/(m^{2}K) was assumed for all windows.	total area of windows in the external walls: 21.3 m^2. Four windows, 1.435 m × 1.635 m each, on the southern and northern elevations. Two windows with dimensions 1.135 m × 0.565 m on the E and W elevations. The heat transfer coefficient U = 1.1 W/(m^{2}K) was assumed for all windows.

Assumptions regarding fuel prices and PV prosumer energy price settlement mechanism in Poland:

- Hard coal, i.e., eco-pea coal with a calorific value of 28 GJ/tonne and a price of PLN 900/tonne;
- Coal had a calorific value of 19 GJ/ton and a price of PLN 450/ton;
- Price of natural gas with a calorific value of 34 MJ/m^3 at the price of PLN 2.2/m^3 (PLN 1.1/m^3 of gas + PLN 1.1/m^3 for gas transmission);
- Electricity price: PLN 0.55/kWh;
- PV prosumer mechanism: on grid installations of 10 kW receiving 80% of the deposited energy within a fixed period of 365 days.

The separate primary data sets were used in the research to extract the data for rural households and SFH. They came from Statistics Poland (GUS), Eurostat, Ministry of Infrastructure and Construction (now Ministry of Infrastructure), Ministry of Agriculture, and National Census of Population and Housing of 2011.

3. Results of Research

3.1. Characteristics of SFH and Energy for Heat Balance in Rural Areas in Poland

3.1.1. Buildings Characteristics

According to the National Census of Population and Housing conducted in 2011 (NSP 2011), there were 5.56 million residential buildings in Poland [36]. Single-family houses (SFH) constituted a significant share of housing mainly in rural areas. In 2011, SFH accounted for 58.72% (3.3 million) of all housing in the rural areas while in the urban areas its share was 31.22% (1.7 million). At the same time, there is a significant difference between the urban and rural residential housing with regard to the average usable area. The useable area is on average larger in the non-urban housing (96.1 m^2) than in the city (62.7 m^2). As far as the age of the buildings is concerned, the SFH are very heterogeneous. Buildings from 1918–1944 accounted for almost 15% of the SFH located in Poland. However, the peak in construction of SFH characterized years after II World War. Buildings from 1945–1970 account for 25% of all SFH. The next two decades added a significant number of SFH, thus the buildings constructed in 1971–1978 and the 1980s account for, respectively, 12% and 13.6% of all SFH in Poland (see Figure 1).

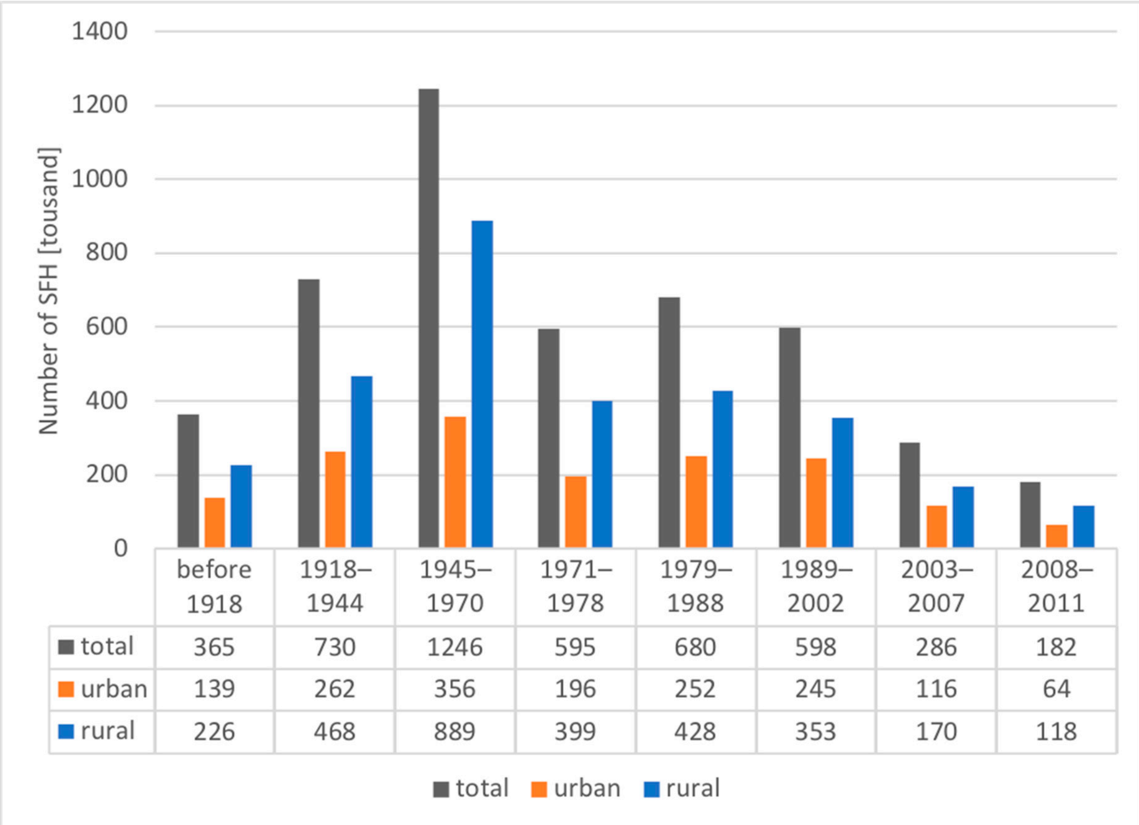

Figure 1. Single-family houses in Poland by construction period.

The age of SFH, or in other words construction technology, impacts an energy balance of a household. It is scientifically proven that investments in more efficient heating systems and thermo modernization of residential buildings, can significantly lower a demand for energy per single-family building and improve environmental standards of these buildings [6,37,38]. Although, studies show that the real size of savings depends also on changes in residents' behaviours [39] as well as climatic zones of selected SFH [37]. In a study regarding SFH in Poland, the authors emphasize that, due to the lower greenhouse gases emissions and lower life cycle costs, wooden SFH can be perceived as more attractive for investments than brick ones [38].

Across the EU, we observe decreasing consumption of heat per m^2 or per dwelling as a result of investments in energy efficient technologies. Climatic conditions and age of residential buildings rank Poland sixth and eleventh among EU countries with the highest heat consumption per m^2 and the highest heat consumption per dwelling, respectively [40].

In Poland the newest SFH buildings, i.e., constructed after 2008, use two times less energy than the same type buildings from 1918–1944. Considering buildings responsible for 25% of all SFH in rural areas, i.e., from 1945–1970, their energy use is 1.7 times higher than of the contemporary ones. At the country level, overall demand for energy for heat is a result of both the age of buildings (which strongly impacts on energy intensity), the total number of buildings constructed in the different time periods and their usable area. Not surprisingly, the highest demand for energy and at the same time, the greatest thermal modernization potential can be found in SFH from 1918–1970. Yet, in this group of buildings, the largest heat consumers are SFH built between 1945–1970 (see Figure 2). More than 71% of them are located in rural areas.

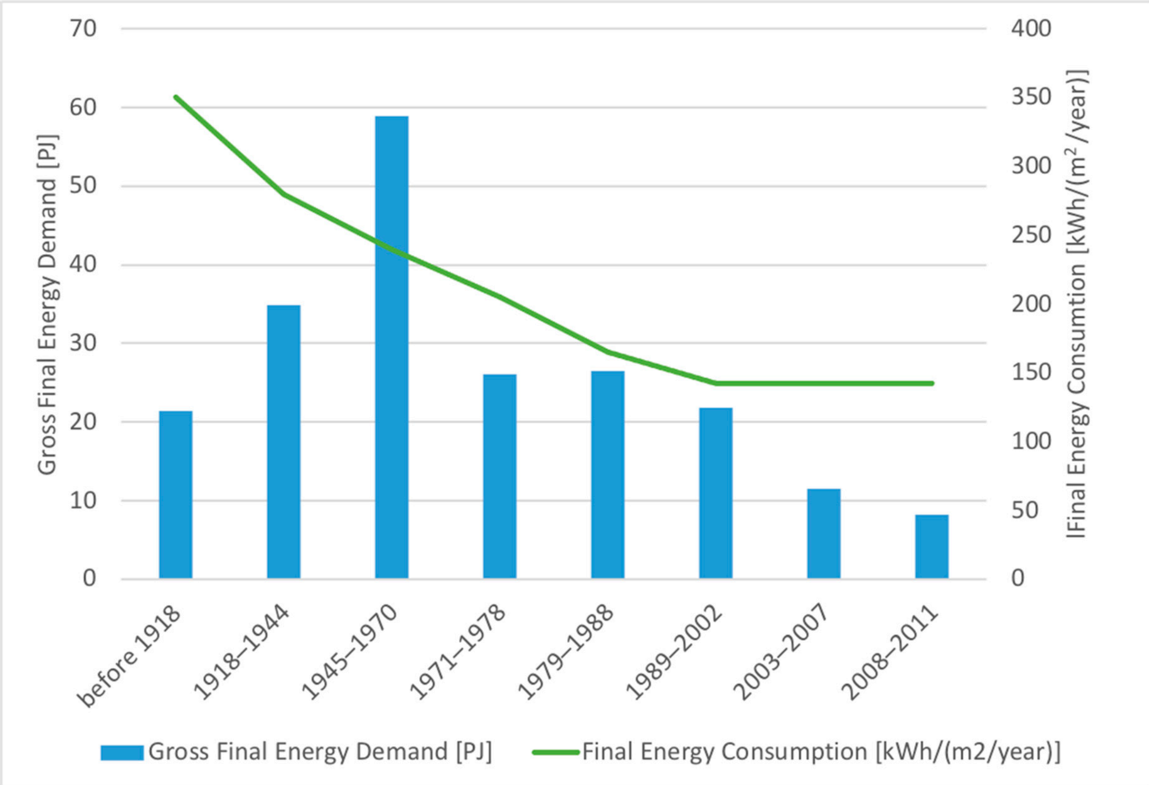

Figure 2. The relation between age and energy demand of SFH (rural) in Poland.

3.1.2. Energy for Heat Consumption Balance in Rural Areas

Regardless the efforts for a deeper and wider diversification of primary energy sources, Poland's energy security still largely depends on coal. In 2018 and 2019 the share of coal (hard coal and lignite) in gross inland primary energy consumption was 48% and 42%, respectively [41,42]. For Polish households' solid fuels, coal in particular, are basic source of energy. In 2018 more than 45% of households in Poland used solid fuels for space heating. These fuels were also used for heating water in 25.6% of households and for cooking in 3.2% of them [43]. Hard coal with 32.1% share in energy consumption per 1 inhabitant, was single most important source of energy for heat. To compare, only 19.6% of energy consumption came from the district heat [43] (p.84).

However, there are significant differences between urban and rural households in Poland in relation to heat sources. According to data for 2012 urban territories were dependent on district heat supply in 59.9%. The second and third most important sources of heat for Polish cities were solid fuels (28.6%) and natural gas (11.5%), respectively. In contrast in the rural areas, households' energy security relied almost entirely on solid fuels, which represented 89.8% of heat consumption. Only 6.2% of heat came from natural gas, whereas the centralized district heat was responsible for around 4% of heat used by the rural households [44] (p. 64). In recent years, the implementation of energy-climate policy in Poland has focused on a large-scale energy system, which are under ETS. In result although some changes could be seen in final energy consumption structure at the country level, from the perspective of rural households not much has changed. As the latest data provided by Statistics Poland show, in 2018 the district heat was commonly used in urban areas with 58.3% of households relying on this source of heat. At the same time, only 3.5% of rural households used district heat. For rural areas, solid fuels remain the most important, basic sources of energy for heat. According to official data, 88.4% of rural households were dependent on solid fuels [43] (p. 59).

It is estimated that coal boilers are a dominant source of heat for SFH buildings constructed from 1945 to 1988. In 2017, boilers and stoves based on solid fuels were the main source for heating in 70% of SFH. In a further 14% of SFH, a wood or other type of biomass boiler was the single most important source of heating [45] (p. 45). Not surprisingly, the use of all kinds of primary energy sources for heat in the buildings constructed before 1980 is higher than in the newer ones. Yet, SFH buildings based on coal show the greatest differences—they use 16% more energy for heat in comparison to the later buildings of the same type, whereas SFH buildings relying on natural gas or district heat consumption of heat is, respectively, 14% and 12% higher than in the buildings constructed after 1980 [44] (p. 64).

3.2. Simulation and Its Results

3.2.1. Heating Costs for Model Buildings

In the research on correlates between the heat sources of a household and final energy costs reduction two variants were adopted: (A) before and (B) after thermal modernization of a single-family building. The two models of SFH were determined in order to assess which of them would provide the best results in energy costs reduction. The first model of SFH is the most common building in Poland, i.e., the so-called "cube". The second one is building constructed in the years 1945–1970—this is the most numerous groups of single-family buildings in Poland. Both models of SFH buildings were created on the basis of the final energy consumption indicator [kWh/m^2 per year] before their thermal modernization. Simulation based on certain assumptions and parameters as described in Section 2. In variant (B)—SFH building after thermo-modernization, the following heat sources were included for analysis: low rank coal, eco pea, natural gas, electricity and heat pump. In the heat pump case, a variant with the integrated photovoltaic (PV) prosumer installation was applied (PV/heat pump system). In this research, an interesting option of biogas was excluded due to a limited number of biogas plants (as for 30 October 2020, there were 99 biogas plants with total installed capacity of 118 MW) [46] and constrains existing in regulatory sphere and supply infrastructure in Poland [10,47].

A "Cube"

As far as the first model of the building, i.e., a "cube" with a flat roof is concerned, the analysis has shown that a comprehensive thermal modernization allows reducing energy consumption by around 81%. Even without replacing the heat source, a "cube" SFH uses only one fifth of the amount of coal or other solid fuel it consumed per year.

The simulation also has shown that thanks to a comprehensive thermal modernization, replacing the heat source so far (i.e., coal boiler) with newer, more effective and less emission-intensive one, but at the same time powered by more expensive fuel—i.e., good quality coal, natural gas or heat pumps—will reduce heating costs. The costs of heating by natural gas in SFH after a comprehensive thermal modernization is reduced by PLN 9304. If the coal boiler is replaced by a heat pump, after thermal modernization the costs of heating will be reduced from PLN 1218 to PLN 705. The costs of heating a single-family building with natural gas will be PLN 3053 less, and with a heat pump PLN 5911 less compared to burning eco-pea coal before the thermal modernization. Yet, the greatest savings can be achieved by supplying the heat pump with electricity produced by PV installation (under prosumer's regime). In such case, heating costs will amount to PLN 705 per year (see Table 2). At the same time, the later combination of technologies results in zero emissions going into the atmosphere.

SFH from 1945–1970

According to simulation a comprehensive thermal modernization of the second, most representative residential building for rural areas, i.e., SFH built between 1945 and 1970, allows energy consumption to be reduced by 65%. The scale of heat costs reduction (after thermal modernization alone) depends on the heat source used in a household. For SFH relying on low-ranked coal, the cost of heat is PLN 1218 per year, which gives PLN 2186 of savings. In the case of eco-pea coal, the cost of heat decreases by PLN 3288 to 1832. In SFH using natural gas for heating, the cost of heat is PLN 3563, which means cost reduction of PLN 6395. Finally, SFH using PV/heat pump installation achieves the lower final bill for heat, i.e., PLN 705, while without thermal modernization the same building energy for heat cost is PLN 1971 (See Table 3).

Table 2. Analysis of the heating costs of a SFH with a flat roof, the so-called "cube".

	Coal	Eco Pea	Natural Gas	Heat Pump	Electricity
Price of fuel	200 PLN/t	900 PLN/t	2.4 PLN/m^3	0.55 PLN/kWh	0.55 PLN/kWh
Costs of energy production [PLN/GJ]	13.30	32.00	70.00	153.00	153.00
Total efficiency of heating system [%]	0.50	0.80	0.90	COP = 2	1.00
Costs including efficiency of heating system [PLN/GJ]	26.60	40.00	77.80	77.00	153.00
Costs before thermal modernization of SFH [PLN]	4399.64	6616.00	12,868.12	12,735.80	25,306.20
Costs after thermal modernization of SFH [PLN]	1218.28	1832.00	3563.24	3526.60	7007.40
Savings [PLN]	3181.36	4784.00	9304.88	9209.20	18,298.80
Prosumer with PV installation				705.32	
Savings [%]	84	89	95	94	97

Table 3. Analysis of the heating costs of a SFH from 1945–1970.

	Coal	Eco Pea	Natural Gas	Heat Pump	Electricity
Price of fuel	200 PLN/t	900 PLN/t	2.4 PLN/m^3	0.55 PLN/kWh	0.55 PLN/kWh
Costs of energy production [PLN/GJ]	13.3	32	70	153	153
Total efficiency of heating system [%]	0.5	0.8	0.9	COP = 2	1
Costs including efficiency of heating system [PLN/GJ]	26.6	40	77.8	77	153
Costs before thermal modernization of SFH [PLN]	3404.8	5120	9958.4	9856	19,584
Costs after thermal modernization of SFH [PLN]	1218.3	1832	3563.2	3526.6	7007.4
Savings [PLN]	2186.5	3288	6395.2	6329.4	12,576.6
Prosumer with PV installation				705.32	
Savings [%]	79	86	93	93	96

Despite the presented results—which show that PV/heat pump installation, even without thermal modernization, is the most cost effective way of heating in second model SFH—a wider application of this technological solution will depend on additional factors. Among them, the existing and future support mechanisms may play crucial role. It is particularly important since significant reductions in heat costs can also be achieved with thermal modernization alone, i.e., without changing the heat source so far.

Potential of Final Energy Consumption Reduction in SFH and Energy Security in Poland

The results of simulation show the existence of significant potential in final energy consumption reduction in rural areas in Poland. It also explains why public policy should be more focused on the question of improving energy and environmental security through responsiveness to the energy needs in the SFH sector.

From a comparative perspective, the residential sector in Poland relies on solid fuels more than in any other EU country. If in 2018 the average share of solid fuels in the final energy consumption for space heating in the EU's residential sector was 4.6%, in Poland this share accounted 44.9% [48]. At the same time, SFHs represent a separate category of residential buildings due to their even higher reliance on solid fuels for space heating. Considering that the share of space heating in final energy consumption in Polish households is 65% [3] (p. 4), investments in improving energy efficiency of SFH should have an impact on reduction of solid fuel use. As shown in Figure 3, at the country level the average potential in final energy consumption reduction in SFH is 40%. This translates into a 3.67% reduction of Poland's final energy consumption. Thus, the improvements in energy efficiency of SFH, especially aged 50 years and more, improve energy security in terms of both its environmental and supply–demand dimension.

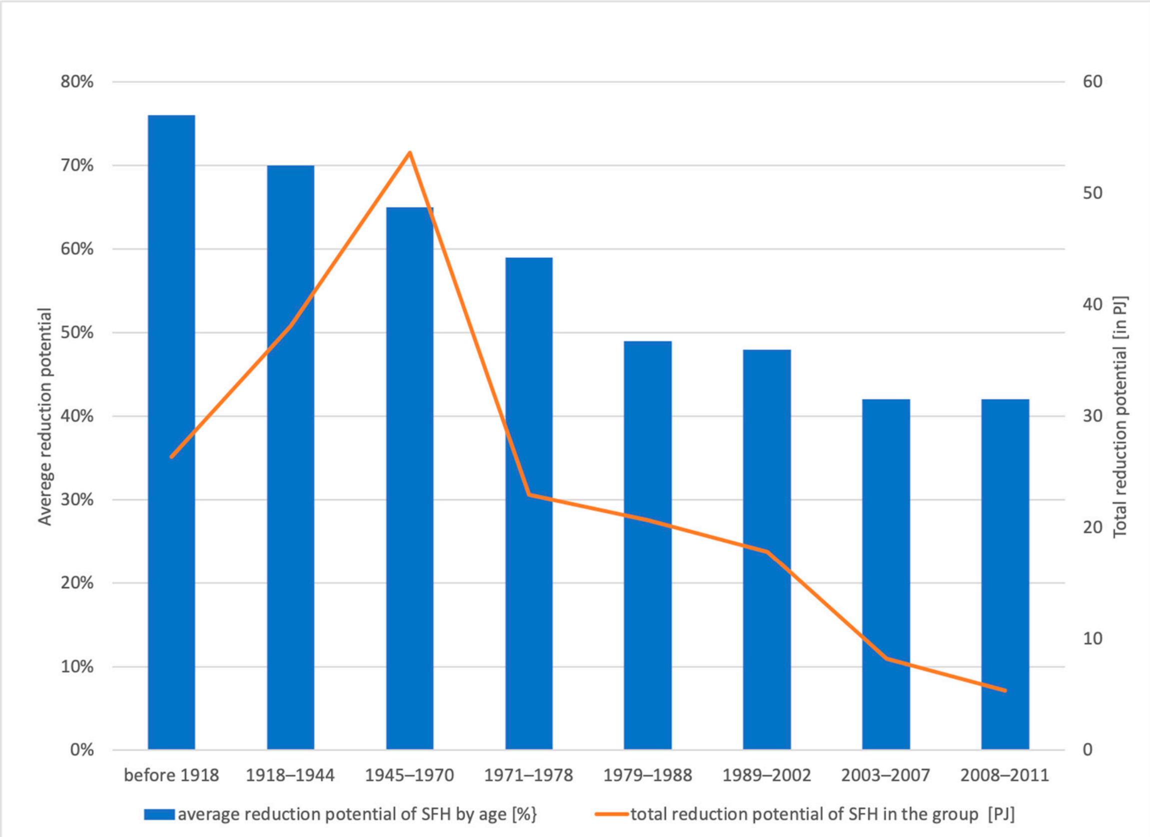

Figure 3. Potential of domestic final energy consumption reduction in SFH.

3.2.2. Changes in the Disposable Income Structure of a Household in Rural Areas

In Poland, some 40% of the population (15.4 million) live in rural areas and for the last 20 years the number of rural inhabitants has been on a steady upward trend. Furthermore, living conditions in rural areas do not diverge considerably from the quality of life of residents of smaller towns (up to 20,000 residents) [49]. At the same time, despite the fact that a share of agriculture in the socio-economic structure of rural areas is on a downward trend an income earned from agriculture activity plays important but diminishing role for rural households. Nowadays, 80% of the rural employed (6.6 million) make on living outside agriculture [50]. After accession to the EU, a process of convergence of income between rural population and non-rural citizens has been observed in Poland. This phenomenon contributed to the fact that a share of people at risk of poverty declined. Nevertheless, there is still income disparity between farming households and non-farming ones. In 2019, a place of residence still strongly differentiates the dynamics and structure of household income and expenditure.

The average monthly disposable income per person in households living in cities was 28.4% higher than in the countryside (by 29.9% in 2018). These differences were due to the level of income received by households, as well as to a higher number of people in rural households. The situation was similar for household expenditure. Spending per person in households living in cities was 34.8% higher than in the countryside (up 34.5% in 2018) [51].

In general, in the period of 2018–2019 annual per capita income growth in Polish households was on upward trend. The average monthly disposable income amounted to PLN 1819 and was 5.0% higher in real terms than in 2018. In turn, the average expenditure per person amounted to PLN 1252 and was higher by 3.1% [51]. It means that the share of expenses in disposable income amounted to 68.8%. Based on available statistical data, it can show that economic situation of Polish farmers in terms of both the average monthly disposable income (PLN 1667) and level of expenditures (PLN 914) was below country's averages The average expenditure was in these households was 27% below the average household expenditure in Poland [51].

The percentage share of expenditure on the use of a flat or house and energy carriers for farmers' households was 13.9%. The costs of energy carriers alone were 9.3% and they included the use of electricity and energy carriers for heat generation and water heating. Wherein the average consumption of electricity consumption per year was 3797 kWh with a cost of PLN 1488 [44]. Among all the expenditure on energy carriers the highest burden is associated with energy for heat which constituted 65.1% of all energy used by household [52] (p. 1).

Average monthly energy (electricity, gas and other fuels) expenditures per capita in households of farmers was PLN 81.28 while the average number of residents in rural households was 3.4 [51]. On the basis of modelling of energy for heat use in SFH constructed between 1945 and 1970 (0.889 million of 3.27 million of residential buildings in rural areas) [36], it is possible to estimate an impact of comprehensive thermal modernization and the change of heat source to PV/heat pump system on the disposable income of rural households. A representative rural household energy and housing spending is PLN 276 per month and PLN 3316 per year. Subtracting the cost of average use of electricity in rural household (PLN 1488) shows that yearly cost of heating is PLN 1828.

Simulation modelling for SFH constructed in years 1945–1970 (see Table 1) shows that heating costs of such building in case of low rank coal use is PLN 3404 while the use of natural gas increases costs to PLN 9958 per year. Compilation of official Statistics Poland data and the result of the simulation modelling exhibit that numerous SFH in rural areas are under heated. Taking into account climate conditions in Poland, especially low temperatures during wintertime, heating comfort is one of key elements of energy security at a household level.

The compilation of the average cost of heating calculated by Statistics Poland, i.e., PLN 1828, and costs of heating in SFH after thermal modernization with integrated PV/heat pump installation, i.e., PLN 705 gives financial savings of PLN 1123 per farmers' household. It means than a representative farmer's family saves PLN 330 per capita per year or only PLN 28 per capita per month. The level of monthly expenditure decrease is 3%, yet the thermal comfort of living increases.

3.3. Current Support Mechanisms for the Thermal Modernization of Buildings and the Development of Prosumerism in Poland—The Role of the CAP Funds

The deep transformation of the economy and clean energy transition must be fair and socially acceptable. It is estimated that more than 50 million households in the European Union suffer from energy poverty [53] due to a combination of high energy expenditure and low household incomes. To address the issue, in 2016 the EU launched its flagship legislative proposal "Clean Energy for All Europeans" under which " ... the consumer will find it easier to invest in renewable energy, most obviously in solar panels, and then consume, store or sell the energy they produce" [54]. Estimates suggest that by 2030, energy communities could own some 17% of installed wind capacity and 21% of solar. By 2050, almost half of EU households are expected to be producing renewable energy [35]. In 2018, energy poverty affected approximately 12.2% of the Polish population, i.e., approximately 4.6 million people [12]. This means that these people do not have sufficient own funds to carry out the insulation of single-family houses or apartments.

Both the EU and Poland offer a number of various publicly financed programs which address the problems of energy efficiency and climate change mitigation. Rising interest in prosumerism has been lately supported by the Polish government via a number of new regulations and aid instruments.

Currently, there are several instruments and domestic programs in Poland to encourage and financially support investors/natural persons interested in increasing the level of energy efficiency in their households and, as a result, reducing expenditure on the purchase of electricity. In general, the central programs offered by the Polish government focus on two areas of support. The first is to support the renovation of existing and under construction single-family residential buildings in order to improve their thermal insulation, the second is to support the development of renewable energy sources in the prosumer system.

In August 2019, the so-called Prosumer Package was introduced in Poland A change was introduced consisting in increasing the permissible capacity of micro-installations from 40 to 50 kW. Definition of a prosumer was extended to include apart from single-family buildings small and medium-sized enterprises, provided that the production of green energy is not their main form of gainful activity. In villages and in urban-rural communes, it was possible to establish energy cooperatives, also with a number of privileges due to prosumers.

The most important privilege of a prosumer is the possibility of settling energy in a cashless, so-called discount system. This system is very beneficial. Cashless billing of the amount of energy under the discount system takes place annually. The generated green energy can be used in real time, covering the current needs of a household or company. In a situation where the amount of energy produced from RES exceeds the current possibilities of its use, the surplus is discharged to the power grid operator.

The bidirectional prosumer counter shows the amount of the receivables, expressed in kWh, at the end of the billing period. Prosumers with installations up to 10 kW and up to 50 kW may receive, respectively, a max. of 80% and 70% of the deposited energy.

Considering the main research objective of this paper it is important to emphasize that from a technical standpoint of view, PV installations can meet the electricity demand only provided they operate within the PV prosumer system based on the grid, which functions as an electricity backup and storage. An additional charge of the "PV backup" solution (20% of the produced energy by the prosumer) was fully taken into consideration in the study and cost calculations.

3.3.1. Clean Air Program

The Clean Air Program [55] is the main program planned for 2018–2029, aiming to contribute to the reduction of emissions to the atmosphere of harmful substances resulting from the combustion of low-quality fuel and the use of obsolete installations in households.

In the planned budget of EUR 23.1 billion, EUR 14.24 billion was allocated for non-returnable subsidies, and EUR 8.9 billion for loans.

For the first time in history, a program could be used to finance single-family housing investments, both already built single-family residential buildings or those under construction. The program covered a wide range of activities, in particular:

- Disassembly and replacement of heat sources;
- Installation of modern devices and installations;
- Installation of renewable energy sources: solar collectors, photovoltaic micro installations;
- Thermal modernization of single-family buildings.

In the first period of operation, a significant limitation was the introduction of the regulation stating that the costs of a photovoltaic micro-installation and solar collectors could be co-financed in 100% only in the form of a loan.

The maximum value of eligible costs, on which the amount of the subsidy is calculated, was set at EUR 12,000. The loans bear a variable interest rate not less than 2% per annum, for up to 15 years. It is possible to combine two sources of financial support, both loans and subsidies [56]

3.3.2. Clean Air Program 2.0

The second edition of the modified Clean Air Program 2.0 [55] began on 21 October 2020. It was aimed at Poles with lower incomes the program offers a higher level of support, extends the implementation period of projects by an additional six months and extends the list of equipment and materials qualified for use. An important element is also the tightening of cooperation between the National Fund for Environmental Protection and Water Management and communes.

According to the new rules, in force from 15 May 2020, natural persons have a chance to receive a subsidy of up to EUR 8500 for the implementation of eco-investments.

Program beneficiaries can apply for support up to EUR 5600 replacing a heat source and installing a photovoltaic installation. If the investment includes a heat pump and a PV installation, it can be even EUR 6750. Moreover, for all beneficiaries, a thermal insulation tax relief of up to EUR 12,000 was introduced.

3.3.3. My Electricity Program

The My Electricity Program [57] results so far include 73,000 applications for subsidies and 408 MW of installed capacity. Thus, as much as 1/3 of the power of prosumer PV sources comes from installations co-financed by the program. The program specifically supporting the segment of photovoltaic (PV) micro-installations.

The budget of the program is EUR 225 million and is intended for non-returnable forms of financing up to 50% of eligible costs of micro-installations, not more than EUR 1125 for one project.

The beneficiaries of the program are natural persons producing electricity for their own needs.

3.3.4. Stop SMOG Program

The applicant in the Stop SMOG Program [58] is a commune which obtains up to 70% of the subsidy for investment costs from the state budget. The program is intended for energy poor people who own or co-own single-family residential buildings.

Scope of the Program:

- Replacement of high-emission heat sources with low-emission ones;
- Thermos-modernization of single-family residential buildings;
- Connection to the heating or gas network.

3.3.5. Agro Energy Program

The Agro Energy Program [59] is addressed towards the agricultural sector the program will run until 2025. The beneficiaries of the program are a natural or legal person who is the owner or leaseholder of agricultural real estate, the total area of agricultural land is in the range from 1 ha to 300 ha and at least one year before submitting the application runs the farm personally or, respectively, conducting agricultural activity or economic activity in the field of agricultural services.

Projects involving the purchase and installation of photovoltaic or wind installations with an installed electrical power of more than 10 kW and not more than 50 kW.

The budget planned for the implementation of the program is approximately EUR 45 million, including up to EUR 38 million subsidies and up to EUR 7 million as a loan.

The amount of support in the form of a subsidy is up to 20% of eligible costs for energy generating installations with a capacity of

- $10 < \text{kW} \leq 30$ up to EUR 3000;
- $30 < \text{kW} \leq 50$ up to EUR 5600.

3.3.6. Increased Use of Photovoltaic Installations in Electricity Generation in Poland in 2018–2019

Over the last two years, Poland has made great progress in popularizing micro-photovoltaic energy sources in the prosumer system (See Table 4). An even faster growth rate is recorded after the first half of 2020. On this basis, it can be concluded that the growing ecological awareness of the inhabitants of Poland, including rural areas, will be the driving force behind the further rapid development of the use of renewable energy sources to satisfy the energy needs of households.

Table 4. Development of electricity production in the prosumer system using photovoltaic micro-installations in 2018–2019 [60].

Year	Number of Prosumers	Installed Capacity in MW	Energy Fed into the Grid in MWh
2018	51,000	344	130,200
2019	149,000	900	325,280
2019/2018 in %	292	262	250

Poland also benefits from EU-funded programs which finance green investments, also in rural areas [61]. In the period of 2014–2020, rural communities in Poland can apply for support under the Rural Development Program 2014–2020 financed from European Fund for Rural Development (EFFRD) of the CAP. RDP in Poland provides for financing of the measure titled Basic services and village renewal in rural areas [62]. Support under this measure covers also investments in renewable energy and energy saving. In Poland, this measure consumed over 1.5 billion euro.

The capacity to adequately reflect the Green Deal Strategy in the EU and finance climate friendly investments depends on a share of the EU budget devoted to its objectives [63]. On 27 May 2020, the Commission put forward two key financial instruments, the Next Generation EU Fund and Multiannual Financial Framework 2021–2027 which is further discussed in Section 4.

3.4. The Perspectives for the Support Mechanisms Development

The European Green Deal (EGD) is a new EU sustainable growth strategy announced in 2019 [35]. The fundamental objective of EGD is to stimulate actions contributing to mitigate negative consequences of climate changes and protect and preserve natural resources for future generations. Efforts need to be taken across the entire economy including industry production, transportation infrastructure and agri-food sector. Changes shall also occur in the area of every-day consumption patterns including diet change and reducing food waste. Furthermore, the delivery of EGD objectives requires reshaping of various public policies to address the climate and environmental challenges and degradation of biodiversity. Both experts and policymakers urge for accelerated public and private investments enabling just and inclusive energy transition leading to climate neutrality objective by 2050. The design of policies and programs, including those dedicated to rural areas, which are to be financed under the new EU budget for 2021-2027 and stimulated by the innovative instrument of NGEU, shall consider the just energy transition and climate neutrality objective of the EGD.

Both the Cohesion Policy of the EU and the Common Agriculture Policy will play a fundamental role to meet the objective of EU climate neutrality by 2050 and contribute to achieving the Union's new 2030 climate targets [64]. As a general principle, all EU expenditure should be consistent with the Paris Agreement objectives [65].

For the last 2–3 years, Poland has been experiencing a strong increase in prosumerism accompanied by the rising environmental awareness of the Polish society. The increase in a number of green investments was possible mainly because Poland has launched a couple of public aid programs promoting and supporting prosumerism. This support shall be continued.

Poland will become of one of the largest beneficiaries of the new Just Transition Fund of the EU to be launched after 2021. It is expected that Poland will receive some 20% of the total allocation of that Fund with a key objective to help Member States to depart from fossil fuels and promote green investments also in rural areas.

4. Discussion

Improvements in thermal modernization and the change of heat source increase energy efficiency and thermal comfort in SFH. This has been proved in many studies regarding different EU countries [6,66,67]. Most of SFH located in Polish rural areas were built between 1945 and 1970. They are characterized by energy inefficiency—their average final energy consumption accounts 240 kWh/m^2/year—and high reliance on solid fuel for heating, including low-ranked coal. The comparison of official data and the results of simulation of heat costs in model SFH buildings showed that single-family houses in Polish rural areas are under-heated. It means that economic surplus is not the only reason behind the decisions to thermo-modernize SFH and change its heat source. However, the price disparities between different primary energy carriers and the financial situation of rural households lead to observation that the changes in disposable income are not significant enough to encourage thermal-modernization and/or the changes of heat source to renewable energy. Moreover, this tendency has been accelerated by the attachment of rural communities to traditional heat sources as well as public policy which has supported replacement of an old coal boiler with a new one (i.e., 5. generation coal boiler). Some studies show the potential role of environmental impulses (including the rising ecological awareness in rural areas), yet in reference to Polish rural areas, and farmers' households in particular, further research in this field should be carried out.

An overview of the existing public policy tools and the support mechanisms proves that the number of incentives has been growing. Yet, the key question should be weather these measures are adequate to meet the ambitions relating to energy and climate policy. An enhancement of economic impulses for Polish rural households to change a heat source to zero-emission one (such as indicated in this study PV/heat pump system) should be more prioritized by decision makers. Considering the development so far of environmental and energy policy regulations and support mechanisms in Poland, one should expect that actions taken at the EU level will be crucial.

The COVID19 pandemic, which hit economies of all EU member states, made the European Commission to propose new ambitious financial instruments. After difficult negotiations of the European Council [68] in July 2020, the final financial proposal was approved. The key instrument to be launched to address economic crisis caused by COVID-19 is the NextGenerationEU Fund (NGEU) designed as a one-off emergency instrument amounting to EUR 750 billion to be put in place for a temporary period and used exclusively for crisis response and recovery. It allows the Commission to raise new financing on the financial markets for 2021–2024. Based on the European Council conclusions in July 2020, the funds borrowed may be used for loans up to EUR 360 billion and for grants up to EUR 390 billion (all in 2018 prices). The Commission will borrow money on behalf of the Union to be repaid after 2027 and by 2058 at the latest. MS will access the Fund via grants and loans. The key instrument under NGEU is the Recovery and Resilience Facility of EUR 672.5 billion of which loans represents EUR 360 billion. The share of the NGEU dedicated to rural development accounts for 1%. All the amounts indicated are to be considered as exceptional budgetary allocations and will not be part of future MFF proposals.

The key instrument to finance the Green Deal will be the EU budget for 2021–2027 (Multiannual Financial Framework) worth EUR 1.074 billion (originally EUR 1.100 billion). Additional funding of EUR 10 billion (originally EUR 30 billion) from the Just Transition Fund of NGEU will be allocated for Climate Action Plan dedicated to green investments.

The CAP with CAP budget (2018 prices) amounting to EUR 356 billion consisting of agriculture and maritime policy is expected to provide answers to a number of rising challenges including climate change and collapse of biodiversity as well as environment and climate action. The CAP aims at ensuring a sustainable agriculture with respect to economic, social and environmental aspects.

The CAP post 2020 must continue offering a number of ways to contribute to climate and environmental objectives. The Member States and stakeholders will have to ensure that the national strategic plans for agriculture and rural development policy financed by the CAP shall fully reflect the goals of the Green Deal. Especially, rural development tools can support the transition via investing in green infrastructure, in knowledge transfer and innovation. The financial proposals provide for a minimum of 30% of rural development funds dedicated towards interventions that address specific environmental and climate-related objectives. To facilitate this process on 20 May 2020, the European Commission announced two strategic documents, i.e., the Farm to Fork Strategy (F2F) [69] and the Biodiversity Strategy [70].

5. Conclusions

Improvements in energy efficiency in the EU's residential sector have already been analysed extensively and presented from different scientific perspectives. Nevertheless, we see the room for studies taking into consideration the specificity of rural areas in different EU countries. From energy and climate security perspectives, investments in energy efficiency and clean energy sources, including zero-emission heating systems, in rural areas can contribute to meeting EU's energy and climate targets. From sustainable development perspective, they can also improve the quality of living of the villagers. Our study contributes to this discussion and shows that single-family houses located in Polish rural areas have a large potential for improving energy efficiency. This is an effect of both the age structure of SFH buildings and the fact that prior to 2017 there were no public policy intervention instruments in this field.

The simulation results for two models of SFH buildings prevailing in rural areas and discussed in this research paper univocally show the existing potential for improving energy efficiency and introducing the new heat sources, including the zero-emission ones (PV/heat pump installation) in rural Poland. The process of changes in supply and consumption patterns would enhance energy and environmental security in rural areas. As far as economic security of rural household is concerned, it has been proved that thermal modernization and change of heat source provide for considerable percentage reduction of heating costs yet, it has a limited impact on disposable income. Analysis of available data for farmer's living in SFH (built in over 1945–1970) also showed only a 3% reduction in total household expenditure. This low impact on disposable income and expenditure of rural household will not encourage improvements in energy efficiency and changes of heat sources in rural SFH. Thus, new public policy measures dedicated to rural areas will be required.

Despite the results, which proved that heat pump driven by PV installation operating in the framework of Polish Prosumer support mechanism is the most cost-effective way of heating in both models of SFH buildings, a wider application of this technological solution will depend on additional factors. Among them, the existing and future public policy support mechanisms will play a crucial role. It is particularly important, since significant reductions in heat costs can also be achieved with thermal modernization alone, i.e., without changing the heat source so far.

Public aid, financed both by the EU and domestic budget, shall be continued in order to strengthen and encourage further changes in energy supply–demand patterns in rural areas. The development of prosumers contributes to mitigating negative implications of climate changes but also improves the economic situation of households in Poland. Reduction of SFH heating costs is extremely important in case of poorer rural citizens. Together with the wide range of aid instruments launched by the Polish government and those supported by EU-financed programs, it shall lead to further development and use of renewable energy sources.

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