

Article

Renewable Energy Utilization in Rural Residential Housing: Economic and Environmental Facets

Aleksandra Siudek ¹, Anna M. Klepacka ^{1,*}, Wojciech J. Florkowski ²  and Piotr Gradziuk ³ 

¹ Department of Economics and Organisation of Enterprises, Institute of Economics and Finance, Warsaw University of Life Sciences, 02-787 Warsaw, Poland; aleksandra_siudek@sggw.edu.pl

² Department of Agricultural and Applied Economics, University of Georgia, Griffin, GA 30223-1797, USA; wojciech@uga.edu

³ Polish Academy of Sciences Institute of Rural and Agricultural Development, 00-330 Warsaw, Poland; pgradziuk@irwirpan.waw.pl

* Correspondence: anna_klepacka@sggw.edu.pl

Received: 24 November 2020; Accepted: 15 December 2020; Published: 16 December 2020



Abstract: Energy and climate policies benefit from modernized construction technology and energy supply source choices. Energy-efficiency improvement and CO₂ emission reduction will result from renewable energy (RE) utilization in new and retrofit single-family houses in rural Poland. Several house construction scenarios and heating energy sources comparing building costs and potential emission reduction are based on already existing structures calculated for a 100 m² dwelling corresponding to the average rural home. With the addition of thermal insulation and RE-generating equipment, construction costs increase, but the energy costs of operating the home dramatically shrink between a conventional and energy-neutral house. The latter scenario includes thermal solar panels and a heat pump as heating energy sources as well as electricity-generating PV panels. Replacing coal with environmentally-friendly RE reduces CO₂ emissions by about 90% annually. Additionally, lower dependence on coal lessens other GHG emissions leading to immediate air quality improvement. New house building regulations guide homeowner construction and heating energy choice, but even larger gains could result from retrofitting existing rural houses, expanding environmental benefits and generating energy bill savings to households. However, the varying climate throughout Poland will require the purchase of energy in winter to assure residents' comfort.

Keywords: renewable energy; rural residential housing; emission reduction; construction regulations; Poland

1. Introduction

The decarbonization of the economy requires multipronged efforts encouraging wide adoption of energy-efficient technologies and the increased utilization of renewable energy (RE) sources. Poland's policies fall in line with European Union (EU) goals and pursue the decarbonization of the economy [1]. The reduction of fossil fuels is part of the energy and climate change policy in Poland, the country most dependent on coal for the production of energy in the European Union [2]. Lowering the use of coal is also the goal of the country's air quality improvement policy because of the substantial negative health outcomes caused by toxic emissions [3]. The dramatic re-structuring of industry in Poland in the last decades led to large reductions in using coal and lowered GHG emissions, especially CO₂ which decreased from 11.164 ton per capita in 1989 to 7.876 ton per capita in 2016 [4]. However, climatic conditions necessitate heating living spaces in homes and apartments from fall until early spring, and even during cool periods at other times of the year. The needs for heating energy vary across the country [5], but are particularly important to occupants of single-family

homes, which prevail in rural areas of Poland and are heavy users of fossil fuels. Rural residents lack opportunities to access piped heating used by 40% of urban households in 2018 [6]. Improvement of life quality and utilization of locally available resources such as RE are the goals of the Strategy of Sustainable Development on Rural Areas, Agriculture and Fisheries for the period 2012–2020 see for example [7]. This strategy reflects the commitment to sustainable development stated in the Polish Constitution (1997, Chapter 1, art. 5).

Heating energy accounts for the largest portion of all household energy expenditures. In the past decade, programs supporting RE utilization by households provided generous subsidies for the purchase and installation of thermal solar panels and rural households participated in the program motivated by energy cost savings [8]. However, the utilization of solar energy installations for single-family homes remains relatively limited. In 2018, one in 52 households used solar energy in Poland [6]. More recently, homeowners could take advantage of subsidies and low-cost loans through participation in a program involving the replacement of coal-using boilers with energy-efficient heating systems including wood pellet furnaces [9]. Such programs reduce heating energy needs in single-family homes, but those needs strongly depend on the construction technology used to build the house. In this context, the adoption of new construction technology mandated by new building regulations takes the concept of sustainable development to a new level. The regulations change construction methods which result in reduction of energy needs of households.

The new regulations are one element of policies aimed at increasing energy security, GHG emission reduction, utilization of RE, and encouraging modern thermal insulation methods in the construction of single-family homes in Poland. The regulations resulted from the EPBD Directive on the energy efficiency of buildings and become compulsory in 2021. The regulations require all newly built houses to achieve zero-energy status, i.e., show zero energy consumption. The EPBD also applies to old buildings. According to the Directive, every potential homeowner receiving a building permit in 2021 has to meet the technical conditions (WT 2021). The new standards apply to all construction projects, including modernization or expansion of an existing building, although some details have not been finalized [10,11].

New regulations are a part of a multipronged approach at increasing energy efficiency that sustain efforts to modernize older rural housing to permanently improve living conditions, local air and environment quality, and assure energy cost savings to households. The requirements in new construction regulations improve the coherence of government programs and allow current or future homeowner to take advantage of several separate programs aiming at energy-efficiency and RE utilization. Additionally, the mandatory building regulations eliminate the resistance to RE, while the subsidy and low-cost loans encourage homeowners who expressed opinions that subsidies for RE-utilizing equipment were important in their decision-making [8]. These approaches lessen rural resident opposition to the use of RE and stronger building regulations while implementing constitutionally-mandated sustainable development.

To provide insight about gains from energy-efficiency enhancement of single-family houses, this study compares investment costs, heating energy costs, and the amount of emitted CO₂ and other GHGs under alternative construction technology scenarios and several renewable and non-renewable energy use setups to heat the living space and domestic hot water. Space and water heating are the main uses of heating energy by Polish households [12]. Heating energy needs result from climatic conditions which are quite complex because of the country's geographical location [13]. The current study assumes the perspective of a predominantly rural homeowner in a country where GDP per capita in PPS is below the EU average [14] complementing research on the European decarbonization pathways analyzing emission reduction and the use of RE at the aggregate level, for example, see [15].

The scenarios include a traditional house heated with coal, traditional house using natural gas, traditional house heated with wood pellets, a house that utilizes RE and thermal insulation, and an energy-neutral house built with the latest construction technology. An average rural house had approximately 108 m² of living space in 2018 [16] traditionally heated with coal. Starting in 2021,

households and the homeowners will face construction regulations requiring all newly constructed buildings to be passive in terms of energy use and equipped with RE micro-installations [17]. Owners of existing houses constructed with outdated technology and using heating systems emitting large amounts of air pollutants can enjoy major energy savings by retrofitting their dwellings by taking advantage of currently implemented government programs. Results from this study provide information for public education campaigns illustrating the cost differences of operating houses using different types of energy as well as the associated reduction in air pollution. Lower toxic emissions instantaneously improve air quality in the immediate neighborhood enhancing life quality and health outcomes and serving as another argument for convincing homeowners to use the best available technical solutions.

The study expands the existing literature that includes research on energy performance of multifamily buildings [18] and the use of gas-powered boilers to heat residential houses in northern Poland [19] or the use of hybrid central heating systems using RE in southern Poland [20]. Moreover, the study considers multiple construction technologies and alternative heating systems. New construction scenarios are supplemented by a discussion of retrofitting an existing rural home with a central heating system utilizing biomass, the most common form of RE in the EU [21]. The selected biomass heating system utilizes wood pellets, a relatively new form of sustainable fuel gaining popularity in Poland.

The study is justified by constant new construction and the existence of a large number of detached houses in rural areas of Poland (more than three million) and emphasizes opportunities for higher energy efficiency, a key element in transforming the energy system in the EU [22]. The focus on single-family houses is also motivated by the portion of households residing in single-family homes increasing by more than 3% between 2005 and 2016 reaching 38.2% [23]. The trend to live in a detached house in Poland, defies the trend towards apartment living in multi-family housing observed in western EU country-members. The trend reflects the generally smaller average living space in Poland than in many other EU countries, but the larger detached house space involves critical decisions regarding energy-efficiency and the choice of heating energy. The consideration of alternative scenarios of building technology and heating energy sources offers insights about newly constructed homes, but also provides information for educating the owners of existing detached rural houses about economic gains from investing in energy efficiency and RE utilization. The study supplements previous research showing the crucial role of engaging owners of single-family houses to lower heating energy needs by using some RE [24]. The case study also develops alternative scenarios estimating the amount of CO₂ emission reduction resulting from new building regulations.

An earlier study found that the greater the benefits to rural communities in Spain, the greater the social acceptance of projects involving the use of RE [25], while a sizable portion of the public did not see obvious benefits from the long-term economic feasibility of RE use in Finland [26]. The absence of public consultation before imposing new construction regulations in Poland forcing the use of RE coincides with the limited information on the benefits and may be interpreted as lacking impartiality. Although the public has generally favorable views of RE in Poland, once the costs of RE use affect the household, attitudes change. The distinction between the general support and local perceptions should be considered suggested a study of German public [27].

2. Rural Housing and Sustainable Growth

Rural areas cover 93% of Poland's territory [28] and rural residents account for 39.9% of the total population and that share has increased 0.7% since 2018. Rural areas are associated with farming and farming dominates the rural economy, but housing construction has been rapidly growing and contributing to local economies. The drivers of the housing construction sector are the desire of many Poles to enjoy their own individual family house as well as the replacement or renovation of existing homes. The first phenomenon results from strict regulations limiting apartment and house size under the former centrally-planned economy and a chronic shortage of accommodation for the expanding population. The generation of "baby boomers" was forced to live in cramped apartments

in urban areas, or share rural houses with parents and grandparents. The never-ending shortage of construction materials severely constrained the ability to enlarge or build new houses even if the size of a rural property could allow such an expansion. The transition to a market-driven economy since 1989 removed restraining regulations, while eliminating scarcities of construction materials and lack of access to updated building technology. The new limitation is the availability of real estate in urban areas, which led to migration to nearby rural areas, where land was less expensive. The majority of the approximately 80,000 new homes built every year in Poland is located in rural areas.

Simultaneously, the abundance of construction material permitted rural residents to either replace their old house or retrofit and enlarge the existing structure. Single-family homes represent 86.3% of all housing in rural areas [29], while multi-family housing accounts for 76.5% of all urban housing [29]. The booming construction in rural areas creates new demands on the energy supply. The construction sector uses about 40% of the world's energy [30]. An average household uses about 65% of purchased energy for space heating and 16.6% for heating water for daily use in Poland. The share of energy used for lighting and cooking is relatively small, 9.8% and 8.5%, respectively. The typical rural household uses more energy than an urban household because of the difference in size. For example, the average size of a rural house living area was 108.1 m² versus 67 m² in urban areas in 2018 [29]. Although many rural residents enjoy large living areas, their incomes are often below those of urban residents which drives their search for the lowest possible energy costs [31].

With scattered settlements of low-density housing, rural areas pose a challenge in the supply of heating energy in Poland. Although 45.8% of multi-family housing in urban areas receive heat from centralized heat-generating plants, the share among rural households was 2.9% in 2018. For example, natural gas was used for space and domestic water heating only in 7.3% of rural households in 2018. The typical rural home is heated with solid fuels, primarily coal used, by 86.2% of households. Rural households used 9.9 million tons of coal and thousands of tons of wood to start the coal fire. Some households using coal-fired furnaces burn plastic and other burnable waste increasing air pollution [32]. A recently enacted regulation allows local government representatives to enter homes in Poland to verify what is being burned in boilers [31]. Inadequate insulation and inefficient furnaces contribute to heat loss and house construction technology is a major factor determining the heating energy requirements.

A sizable share of rural homes was constructed before 1961 when regulations allowed the thermal efficiency of $k < 0.87$. Rural homes built between 1961 and 1995 represent 51.8% of housing and had to meet higher requirements of $k < 0.3$. Since 1996, another 14.5% of houses were built in rural areas, still under the requirement of $k < 0.3$. New regulations placed in 2008 increased thermal efficiency requirements to $k < 0.25$ [33]. Since then, new regulations follow the guidelines adopted by the European Commission [34].

The new construction requirements provide strong incentives to use RE, e.g., solar thermal panels, wood pellet boilers, and heat pumps for home heating systems and PV panels for generating electricity. The recently introduced programs offer subsidies and low-interest loans for replacement of home heating systems and are specifically addressed to single-family homeowners and those building new homes [9]. However, the response to the program operating since January 2018 has been minor [6]. The results of this study provide evidence of the substantial long-term economic gains through cost reduction of operating a house and can be applied to popularize the program. An increased participation in the program directly achieves the goal of local air quality improvement and extends contributions to national and EU energy and climate policy implementation. As a result, the consideration of alternative building technologies with a focus on the type of energy used involves the economic, social, and environmental aspects of sustainability.

The social acceptance of new building regulations determines the future compliance and the use of RE in new homes. Moreover, once the homes constructed using the modern technology guided by recent regulations [35] appear in rural landscape, the owners of the existing houses are more likely to undertake thermal modernization of their residencies. The living comfort in an energy neutral house,

the convenience of purchasing heat-generating energy, and largely eliminated disposal of ash have an unquestionable appeal. With the social aspect of sustainability in the background, the focus shifts to the economic and environmental aspects.

3. Methodology

3.1. House Construction Scenarios

The case study presents three scenarios involving the use of different construction methods. All of the scenarios involve fully completed and closed structures and include the installation of all windows, external doors and the door to the garage. Additionally, the scenarios also include insulation of the roof. However, the energy-efficiency of the insulating materials varies depending on the scenario. Each of the single-family house scenarios is equipped with heating systems utilizing fossil fuels and different RE sources. The comparisons also include the use of electricity supplied from the grid.

3.2. Building Model

The average living space of a single-family rural home according to the National Census summary was almost 97 m² in 2002 and increased to 101.8 m² in 2011 [36]. The average living space has been gradually increasing over time and reached 108.1 m² in 2018. However, many newly built detached houses have a floor plan much larger than the existing homes as indicated by the national average of 143.5 m² in 2018 [37]. The ever-changing living space alters heating needs, although regional climate variation may shorten or extend those needs in Poland. The current study assumes a single-family home with 100 m² of living space and the calculations provide a benchmark that allows for adjustments for specific homes. Another simplification is the application of a house plan that is a rectangle and includes a garage as a part of the building. The house is a duplex with a functional second story (attic) and a gabled roof. Such design is common in rural areas among newly built and existing homes. The typical house occupies a flat and open terrain; most newly constructed homes are not on farms and contrast with older rural houses of farming families that are typically surrounded by buildings on the same property. The model building is heated using radiators mounted on the walls. The space heating equipment also provides the hot domestic water. The building plan does not include a basement or a cellar.

3.3. Construction Costs

Information about construction costs, costs of RE micro-installations, costs of a coal-fired furnace, and exterior wall and roof insulation were obtained from publicly available sources (see Appendix A). The scenarios include separate estimates of the annual costs of supplying the family with hot domestic water and heating the living space, the two main energy-related expenses for households in Poland. Calculations use energy prices reported by the Central Statistical Office (GUS). The alternative construction scenarios include the same major elements: building the shell of the house, installing windows, doors, roof insulation, and the heating and energy supply fitting. Although prices of construction and insulation materials vary between regions, those variations are usually negligible. Any reductions in costs that suppliers can achieve through market segmentation generally do not exceed transportation costs. Some potential homeowners in rural areas, for example, may save on labor costs if they choose to perform some tasks such as the installation of roof insulation or doors, but the savings are relatively small. The summarized costs are for the same building plan, but differ in the amount, type and energy-efficiency of selected materials and, wherever applicable, the associated labor costs.

3.4. Evaluation of CO₂ Reduction Emission

The indicators of CO₂ emissions for various sources of energy used by a single-family dwelling were obtained from the National Center for Emission Accounting and Management [3]. In the case of coal, the emission indicator was 94.7 kg/GJ and for natural gas it was 56.1 kg/GJ. The indicator

associated with electricity that a house will have to purchase, especially during the long heating season, was 93.87 kg/GJ. The study follows the Ministry of Infrastructure and Development methodology for establishing energy features of a house or a part of a house issued on 27 February 2015 [38].

3.5. Calculation of Reduction of Other GHG and Particulate Emissions

Currently, the majority of rural homes use coal in inefficient residential stoves to heat the living space and domestic water. Burning coal emits NO_2 and SO_2 [39] as well as particulate matter, a well-recognized problem in Poland [40]. The emissions negatively affect health [41,42], including that of children [43]. The reduction estimates of selected toxic emissions supplement the measures of environmental benefits associated with the new building regulations.

4. Results

4.1. Construction and Thermal Insulation Costs

The construction of the shell of the building includes the ground preparation, construction of foundations, external walls, chimneys, ceilings, roof construction and cover, and gutters (Table 1). Sustainable growth in single-family home construction begins with the initial investment. The use of conventional construction technology is less expensive than the energy-neutral technology, but the differences in material used to construct external walls reveal energy-efficiency gains.

The conventionally-built home uses a brick type characterized by the heat transfer coefficient $U = 0.35 \text{ W/m}^2\text{K}$ and drops to $U = 0.31 \text{ W/m}^2\text{K}$ for the other two scenarios (where the lower value implies better insulating properties) (Table 1). The least expensive scenario includes thin external wall thermal insulation, and the costs increase for other scenarios. The energy-efficient home has an insulation layer of material 12 cm thick, while the energy-neutral home's wall insulation is 18 cm thick with higher insulating value. The material costs increase by 50% in the energy-efficient house variant and nearly triple (an increase of 283.3%) in the energy-neutral scenario. Labor costs increase by 89.5% for the two scenarios as compared to the conventional construction, but the energy efficiency improves substantially as the heat transfer coefficient decreases from $0.28 \text{ W/m}^2\text{K}$ to $0.15 \text{ W/m}^2\text{K}$.

Once the shell of the house is completed, the major factors contributing to the total construction costs are related to the energy efficiencies of the three types of homes (Table 1). Windows, doors and the garage door installation completes the house and allows for the interior work on the house (not considered here). A conventional house is equipped with PCV double-pane windows with the heat transfer coefficient $k = 1.4$. More energy efficient widows with $k = 1.1$ are installed under the next scenario, but triple pane windows with $k = 0.85$ are installed in the energy neutral house. The cost differences are substantial and compared to the traditional home, the energy-efficient scenario lists window costs, respectively, 206.6% and the energy neutral 412.8% higher. Labor costs are only 25% higher in the energy neutral case because of the more involved installation. The door selected for the conventional house costs about a third of the entrance door installed in the energy neutral home and almost 60% of the door in an energy efficient house.

The labor cost difference in mounting the garage door is large in relative terms, 33.3%, but small in absolute terms between the first and the other two scenarios (Table 1). The garage doors installed in the three scenarios differ in their insulating capacity ($U = 1.6 \text{ W/m}^2\text{K}$ vs. $U = 1.1 \text{ W/m}^2\text{K}$ vs. $U = 0.9 \text{ W/m}^2\text{K}$) and the model, a single vs. segmented door. The interior thermal insulation of the attic differs only in the cost of the material since the labor cost is the same under all scenarios.

The last item of closing the structure is the cost of insulating the roof. The heat transfer coefficient of the insulation, $U = 0.036 \text{ W/m}^2\text{K}$, is identical for the two scenarios and there is a difference in the thickness of the mineral wool layer (Table 1). The energy-neutral house uses a different insulation, polyurethane (PUR) foam, characterized by $U = 0.023 \text{ W/m}^2\text{K}$. With the labor costs identical for the three scenarios, the cost difference is in the amount and type of materials, and the cost more than triples (327.7% higher) in the case of the energy neutral house as compared to the conventional scenario.

Table 1. Building stage and costs of materials and labor for three construction technologies applying different thermal insulation and heating and supplementary energy supply systems for a single-family home with 100 m² of living space, Poland, 2020.

Construction Stage	Traditional Construction	Energy-Efficient Construction	Energy Neutral Construction
Ground preparation, foundations, insulated floor on the ground	Concrete sleeper on compacted soil, moisture barrier, a 5 cm Styrofoam layer, floor screed M = 16,000 PLN; L = 22,000 PLN; M + L = 38,000 PLN (8877 EUR)	Concrete base on compacted soil, moisture barrier, a 15 cm extruded polystyrene EXP layer, floor screed M = 27,500 PLN; L = 22,000 PLN; M + L = 49,500 PLN (11,563 EUR)	Foundation plate with thermal insulation performing the floor function set on the ground surface M = 31,000 PLN; L = 20,000 PLN; M + L = 51,000 PLN (11,915 EUR)
External walls	Single layer wall made of blocks of autoclave aerated concrete (AAC) 36.5 cm in length with U = 0.035 W/m ² K and covered with cement-gypsum M = 12,000 PLN; L = 9500 PLN; M + L = 21,500 PLN (5023 EUR); External wall U = 0.28 W/m ² K	Double layer wall of ceramic blocks 25 cm P + W with U = 0.31 m ² K + 12 cm Styrofoam with U = 0.035 W/m ² K + thin-layer plaster M = 25,000 PLN; L = 18,000 PLN; M + L = 43,000 PLN (10,045 EUR); External wall U = 0.23 W/m ² K	Double layer wall of ceramic blocks 25 cm P + W, U = 0.31 W/m ² K + layer of graphite polystyrene 18 cm thick and U = 0.031 W/m ² K + thin-layer plaster M = 34,000 PLN; L = 18,000 PLN; M + L = 52,000 PLN (12,147 EUR); External wall U = 0.15 W/m ² K
Chimneys	M = 6000 PLN; L = 2000 PLN; L + M = 8000 PLN (1869 EUR)	M = 3500 PLN; L = 500 PLN; L + M = 4000 PLN (934 EUR)	M = 3500 PLN; L = 500 PLN; L + M = 4000 PLN (934 EUR)
Monolithic ceiling, reinforced concrete	M = 26,000 PLN; L = 9000 PLN; L + M = 35,000 PLN (8176 EUR)	M = 26,000 PLN; L = 9000 PLN; L + M = 35,000 PLN (8176 EUR)	M = 26,000 PLN; L = 9000 PLN; L + M = 35,000 PLN (8176 EUR)
Timber roof truss	M = 7500 PLN; L = 8000 PLN; L + M = 15,500 PLN (3621 EUR)	M = 7500 PLN; L = 8000 PLN; L + M = 15,500 PLN (3621 EUR)	M = 7500 PLN; L = 8000 PLN; L + M = 15,500 PLN (3621 EUR)
Roof initial covering, soffit boards, gutters, etc.	M = 4500 PLN; L = 5500 PLN; M + L = 10,000 PLN (2336 EUR)	M = 4500 PLN; L = 5500 PLN; M + L = 10,000 PLN (2336 EUR)	M = 4500 PLN; L = 5500 PLN; M + L = 10,000 PLN (2336 EUR)
Roofing	Steel tile M = 6150 PLN; L = 4100 PLN; L + M = 10,250 PLN (2394 EUR)	Ceramic tile M = 9500 PLN; L = 9500 PLN; L + M = 19,000 PLN (4439 EUR)	Ceramic tile M = 9550 PLN; L = 9500 PLN; L + M = 19,000 PLN (4439 EUR)

Table 1. Cont.

Construction Stage	Traditional Construction	Energy-Efficient Construction	Energy Neutral Construction
<i>Closed house shell</i>			
Windows	Double-pane PCV windows, $k = 1.4$ M = 7480 PLN; L = 2500 PLN; M + L = 9980 PLN (2331 EUR)	Double-pane PCV windows, $k = 1.1$ M-12,950 PLN; L = 2500 PLN L + M = 15,450 PLN (3610 EUR)	Triple-pane PCV windows, $k = 0.85$ M-24,050 PLN; L = 3000 PLN; (warm assembly), L + M = 31,550 PLN (7370 EUR)
Entrance door	Door with $k = 1.7$ M = 1850 PLN; L = 450 PLN L + M = 2300 PLN (537 EUR)	Door with $k = 1.5$ M-3100 PLN; L = 600 PLN L + M = 3700 PLN (864 EUR)	Door with $k = 1.3$ M = 5500 PLN; L = 600 PLN; L + M = 6100 PLN (1425 EUR)
Garage door	Up-and-over garage door with a drive, $U = 1.6 \text{ W/m}^2\text{K}$ M = 2250 PLN; L = 1000 PLN, M + L = 3250 PLN (759 EUR)	Sectional garage door with a drive, $U = 1.1 \text{ m}^2\text{K}$ M = 4650 PLN; L = 1000 PLN, M + L = 5650 PLN (1320 EUR)	Sectional garage door with a drive, $U = 0.9 \text{ m}^2\text{K}$ M = 9600 PLN; L = 1000 PLN M + L = 10,600 PLN (2475 EUR)
Attic insulation	Mineral wool, 10 cm layer, $U = 0.036 \text{ m}^2\text{K}$ M = 2500 PLN; L = 4350 PLN L + M = 6850 PLN (1600 EUR)	Mineral wool, 15 cm layer, $U = 0.033 \text{ m}^2\text{K}$ M = 3200 PLN; L = 4350 PLN L + M = 7550 PLN (1765 EUR)	Rigid PIR foam board 10 cm thick, $U = 0.023 \text{ m}^2\text{K}$ M = 10,693 PLN; L = 4350 PLN; L + M = 15,043 PLN (3515 EUR)
<i>Heating and supplementary energy equipment installation</i>			
Central heating	Central heating installation with a gas boiler for natural gas M = 7200 PLN; L = 8000 PLN L + M = 15,200 PLN (3551 EUR)	Central heating system with a gas condensing natural gas boiler M = 13,000 PLN; L = 8000 PLN L + M = 21,000 PLN (4905 EUR)	Central heating installation with a ground heat pump M = 28,000 PLN; L = 8000 PLN L + M = 36,000 PLN (8411 EUR)
Supplementary energy supply sources	None	Thermal solar panels M = 22,000 PLN; L = 5000 PLN M + L = 27,000 PLN (6310 EUR)	PV panels, 6 kW capacity M = 28,000 PLN; L = 7000 M + L = 35,000 PLN (8175 EUR)
Radiators	Radiators M = 4500 PLN; L = 3000 PLN L + M = 7500 PLN (1750 EUR)	Radiators M = 4500 PLN; L = 3000 PLN L + M = 7500 PLN (1750 EUR)	Low-temperature radiators, preferably flat M = 8000 PLN; L = 3000 PLN L + M = 11,000 PLN (2570 EUR)
Ventilation	Gravity ventilation L + M = 1000 PLN (233 EUR)	Mechanical ventilation M = 11,000 PLN; L = 3000 PLN; M + L = 14,000 PLN (3271 EUR)	Mechanical ventilation + heat exchanger M = 11,000 PLN + 9420 PLN; L = 3000 PLN; M + L = 23,420 PLN (5472 EUR)

Note: L—Labor, M—Material. Source: Calculations based on [44–57].

4.2. Heating System and Electricity Supply

The primary source of heating energy and hot water is a natural gas-operated boiler in the conventional home. The energy-efficient home is equipped with a gas-fired double function condensing boiler. Both scenarios imply that a rural resident has access to piped natural gas. Access to piped gas in rural areas is increasing but still infrequent in Poland. In some regions, especially those with local natural gas deposits, the use of gas-fired boilers is realistic. Rural residents could use LPG tanks that must be periodically refilled, but the weather pattern in winter months determines the refilling frequency and two gas explosions in November 2020 in homes heated by LPG indicate the possible problems in operating such systems. The differences in costs of these systems are not considered in the current discussion. The energy neutral home obtains heat energy using the geothermal heat pump, which is the primary reason for the nearly three-fold increase in equipment costs. Specifically, the boiler cost of 7200 PLN (1692 EUR) in the conventional house scenario increases to 28,000 PLN (6542 EUR), or 288.9% more, when choosing a geothermal heat pump. Interestingly, labor costs are basically the same regardless of the homeowner's choice of the heating system. Space heating involves radiators in the case of the conventional and energy-efficient house, and flat, low-temperature radiators in the case of the energy-neutral house.

The energy-efficient and energy neutral homes utilize RE in the form of solar radiation. The energy-efficient home uses thermal solar panels, while the energy neutral house uses PV panels with the capacity of 6 kW. The panels are intended as the supplementary source of energy to power the heat supply system. Under Poland's climatic conditions and depending on the region, an energy neutral house will likely require a purchase of electricity during the months when the demand for heat is particularly high because of the scarcity of solar radiation. In Poland the available solar radiation is most scarce during the periods of highest demand for space heating [58]. The energy neutral house will generate surplus electricity in other periods because the solar radiation is typically higher, while the heating needs are limited to the use of hot water. On balance, the home will offset electricity purchase with the supply of electricity to the grid.

Finally, the costs of house ventilation are lowest in the case of using a gravitational system in the conventional house, but 11 times higher when the energy-efficient house uses mechanical ventilation (Table 1). The mechanical ventilation system in an energy neutral house is even more pricey and includes the heat exchanger for the total cost 24 times higher than in the conventional home.

4.3. Total Cost Differences

Table 2 summarizes the total costs of building a single-family 100 m² house using the three construction technologies and three choices of the central heating system. The costs for various construction stages are listed in Polish zloty and euro. The cost of construction of the unfinished energy-efficient house is 44.5% higher than a house using traditional technology. The costs are 182.8% higher in the case of an energy neutral house. The cost of the heating system and the supplementary electricity source for an energy neutral single-family house is a staggering 353.2% greater than that of a rural house having access to piped natural gas, which reaches a fraction of the rural population.

Table 2. Construction costs of a single-family house using alternative construction technologies and energy, in Polish zloty (PLN)/euro.

Construction Costs	Traditional House	Energy-Saving House	Energy-Neutral House
Closed unfinished house	22,380/5229	32,350/7558	63,293/14,788
Heating and supplementary energy equipment installation	23,700/5537	69,500/16,238	107,420/25,100
Total cost ^a	183,830/42,951	272,850/63,750	356,713/81,650

^a Assumes a single-family house has 100 m². Note: Exchange rate as of November 15, 2020: 1 euro = 4.2807 Polish zloty [59].

4.4. Heating Energy Needs under Alternative Construction Scenarios and Retrofit Options

In the conventional house common in rural areas, the heating system utilizes coal and often serves a dual purpose of heating the space and domestic water. Maintaining the room temperature requires constant monitoring and adding coal. Coal not only generates a sizable volume of ash, but ash disposal involves additional fees. However, the annual cost of heating space and domestic water is lowest, slightly outperforming the use of natural gas (Table 3). The use of natural gas does not require constant monitoring and eliminates the removal and disposal cost of ash. Given the lack of access to natural gas in rural areas, a wood pellet boiler offers an alternative. Wood pellet is a rather novel energy source available for household use and the specialized boilers require less frequent monitoring than the coal boiler does, while the amount of ash is a fraction of that resulting from coal burning. Wood pellets generate substantial environmental benefits because they are a locally available RE supplied by manufacturers located mostly in rural areas. Moreover, the wood pellet ash can be readily applied as fertilizer [60] in landscape surrounding a single-family home. The convenience of wood pellet use is countered by the higher total costs of supplying the house with heat energy as compared to coal (30.5% more) or natural gas (22% more) (Table 3).

Table 3. Energy generation costs for domestic water and central heating systems for homes built using alternative technologies and using different energy sources scenarios in PLN and euro.

Heating Purpose	Traditional House (Coal)	Traditional House (Natural Gas)	Traditional House (Wood Pellet)	Energy Saving House (Natural Gas + Solar Panels)	Energy-Neutral House (Heat Pump + PV)
Domestic water system	4404/1029	3779/883 ^a	5118/1196	3779/883	148/34
Central heating system	4007/936	5217 ^b /1219	5860/1369	864/198	766/179

Note: The exchange rate on 15 November 2020 was 1 euro = 4.2807 PLN [59]. ^a Price of 1 kWh generated from natural gas is 0.25 PLN as listed by Viessman. ^b Price of 1 kWh from electricity is 0.65 based on [16].

The annual costs of heating energy are substantially less in the case of the energy-efficient house. Those costs are 44.8% less than the coal-using traditional house, the least expensive scenario (Table 3). In the case of an energy-neutral house the energy costs of heating space and domestic water amount to only 879 PLN (205 EUR), or 10.5% of the cost of heating the single-family traditional house with coal. The calculations in the current study disregard the possible costs of routine maintenance.

The heating energy needs vary dramatically for various types of houses (Appendix B, Tables A1 and A2). A traditionally built house that uses a coal-fired boiler is estimated to require 31,909 kWh heating energy per year. By switching to the use of natural gas as the energy source, the requirements drop by 37.6%. An energy efficient house that is equipped with a RE installation requires 83.4% less heating energy than the coal-heated house. Those needs drop by 86% in the case of an energy neutral house (Table A1). The cost of the annual needs of heating energy depend on prices suggesting that heating with coal is (15.6%) less expensive than using the environmentally friendly natural gas coal has been traditionally a secure and affordable energy in Poland [61]. The calculations do not account for the convenience associated with the use of natural gas and assume that the piped gas is available at rural locations. The energy savings are slightly larger when the traditional house is heated with natural gas, but since that option is available only to a fraction of rural homes such comparison is less realistic.

The boiler heating water requires an electric pump to force water circulation. The traditional house with a coal-fired boiler necessitates 334 kWh annually of auxiliary electricity supply, 8% less than when using natural gas (Table 1). Under the considered construction scenarios, the corresponding costs of energy production drop from 4404 PLN (1029 EUR) in a traditional house that depends on coal to 766 PLN (179 EUR) for the energy efficient and energy neutral houses, or 86.4% less.

4.5. Changes in CO₂ Emission

The sustainability principle is well served by the reduction in emissions stemming from the use of modern construction technology and heating energy source. The traditional coal heated house emits about 165% times more CO₂ than a similar house heated with natural gas (Table 4). The traditional coal-using house considered in this study already includes energy-efficiency supporting upgrades such as insulated windows, doors, external wall insulation and an insulated roof. However, among more than three million single-family houses in rural areas, many still have not completed such upgrades, while using the inefficient coal-burning boilers.

Table 4. Annual emissions for single-family rural house construction scenarios.

Construction Technology	CO ₂ kg/m ² /year	SO ₂ kg/year	NO ₂ kg/year	PM _{2.5} kg/year	PM ₁₀ kg/year
Traditional house (coal)	199	23.8	20.4	6.7	7.6
Traditional house (natural gas)	75	15.1	6.4	6.5	8.3
Traditional house (wood pellet)	0.8	0	0	1.9 ^a	2.1 ^a
Energy-saving house (natural gas and passive solar panels)	25	10.5	5.25	4.7	6.3
Energy-neutral house (geothermal heat pump and PV panels)	5	0	0	0	0

^a g/kg of burned wood pellet.

Switching to a wood pellet boiler nearly eliminates CO₂ emissions because the burning recycles the gas already absorbed by wood from the atmosphere [62]. The only emissions associated with the use of wood pellet boiler is the electricity needed to operate it causing that heating RE energy option to emit 0.8 kg/m²/year.

A house built with energy-efficiency in mind and enabled to use RE in the form of thermal solar panels generates 87.5% less CO₂ than a traditional house heated with coal (Table 4). The energy neutral house releases 3.5% of CO₂ volume emitted by a traditional house heating with coal but more than a house equipped with a wood pellet boiler (Table 4).

4.6. Changes in Toxic GHG and Particulate Emissions

Rural houses in Poland that use the inefficient coal furnaces or boilers are a source of emissions including SO₂, NO₂, PM_{2.5}, and PM₁₀. The health effects of those emissions are wide in scope and well established. For example, rural children exposed to GHG and particulate matter (PM) have higher risk of developing Type 1 diabetes [63]. The energy neutral house does not emit any toxic gases to its immediate neighborhood. The amount and composition of emissions associated with that type of a house depend on the energy source used to supply the house with electricity. However, the energy efficient house or a traditional house heated with natural gas generates gases other than CO₂.

Of particular interest to rural homeowners is the use of biomass in the form of wood pellet. Compared to coal, a kilogram of wood pellet emits 22.5% less NO₂ [64]. Finally, wood pellet emits 96% less particulate matter than coal. The actual differences in GHG emission reduction depend on the energy-efficiency of the specific model of the boiler. The use of natural gas, infrequent in rural areas, also substantially reduces GHG emissions. Heating with the gas condensing natural gas boiler emits 0.001% of SO₂ as compared to a coal-fired boiler and virtually no particulate matter [65].

5. Discussion

The desire to own a family home will drive Poland's potential homeowners to build their new house, primarily in rural areas due to space availability. The calculated building costs (Table 1) must be considered in the context of the household ability to finance the construction. The cost difference between the single-family home built using the conventional technological solutions and the energy-neutral house is much larger than similar differences reported in studies in other countries. For example, the cost difference between the standard house built in accordance with Belgian regulations and a low-energy house (roughly comparable to the energy-efficient house considered here) was 4% and a passive (energy neutral) house 16%, respectively [66], while the difference between a standard and a passive house amounted to 10% in Germany [67]. Both studies suggest a considerably smaller relative differences between a conventional house and its energy-efficient alternatives established in the scenarios considered in the current study.

Mortgage financing has a bad reputation in Poland since the financial crisis of 2009–2010 because although the continuing GDP growth contrasted with the global malaise, many families suffered [68]. Prior to the financial crisis, banks offered mortgages priced in Swiss francs. The Swiss franc rapidly appreciated during the crisis and dramatically increased the mortgage debt servicing. The repercussions of that phenomenon are still felt today. Such recent memories combined with the shock in the ongoing COVID-19 pandemic and the induced economic slowdown affect households' attitudes discouraging the long-term credit-financed investment.

A number of future homeowners may not qualify for mortgage financing given the average income in rural households in general. Regional income disparities also persist. The lack of access to mortgage financing suggests the already observed prolonged construction because a rural households and their owners is likely to accumulate savings and then use them to finance the construction in stages. For example, the first stage will be limited to the unfinished house without the external wall insulation, windows and door. The last stage could involve the central heating system installation. An extended construction potentially delays the occurrence of gains to the household and the environment.

The large initial investment in the energy neutral house is expected to eliminate the cost of energy purchase to heat space and water. Those costs account of the about 60–70% of the cost of total energy purchase by an average household in Poland. The share is much larger than in many other EU countries or in the United States. An earlier study showed that the motive to save on the monthly energy bill was a major motive in the rural household investment in the thermal solar panels [8]. However, the rural homeowners mentioned the cost of RE utilizing equipment as a constrained and viewed the subsidy as important.

The currently operating furnace replacement program offers subsidies for qualifying households if they choose to replace their old furnace or boiler. The subsidy is matched to per capita income in the household and is proportionally larger for those with least income. The program aims at the improvement of energy-efficiency by households and includes, besides furnace replacement, subsidies to window and door replacement as well as external wall and roof insulation. The program also offers low interest loans for those who do not qualify for a grant. The program is more attractive to retrofitting an existing single-family home and less to future homeowners.

The comparison of the three construction technologies and the use of various insulating materials provides important knowledge to consider by future homeowners, but also by the owners of the existing rural family homes. Splitting the various construction stages (Table 1) demonstrates the costs associated with the use of alternative insulation. A retrofit of an existing house could involve specific projects. Among the largest is the resignation from a fossil-fuel based space and water heating system and its replacement by the RE-based installation such as wood pellet furnace. A retrofit generates potentially substantial savings to the household and the largest environmental benefits. The reduction of CO₂ emission contributes to the national and EU climate policy and represents a direct contribution from households. The energy neutral house eliminates the emissions of NO₂, SO₂ and particulate matter comparison to the coal-heated single-family dwelling. The obtained energy savings, environmental

benefits, and economic gains support the conclusion that the thermo-modernization of a single-family rural residence and the modernization of the heating source bring direct economic gains to a household, indirect benefits in the local air quality improvement, and long term benefits in health benefits and environmental quality.

Limitations of the Study

The building model considered in this study assumes a simple floor plan and is limited in size. Many newly constructed houses are larger and there is a great variety of floor plans. Variation in the age, construction technology, and floor plans pose a challenge for thermal modernization of existing rural family homes. Although some parts of the house may be thermally insulated—for example the roof—other parts, like the internal partitions, would have to be rebuilt creating a domino effect forcing the renovation of several areas of the house. Improving the thermal insulation between various floors excludes portions of the house from use for the duration of the project. As a result, the thermal insulation project for an older house may cost more than a similar project for a new house.

The analyzed construction costs use the price lists reflect the asking price of local suppliers. Ultimately, prices of all building materials and heating systems may be both negotiable and region-specific. Consequently, the actual construction costs are likely to deviate somewhat from those considered here. Another source of price variation are changes in price level, which may have been affected by the ongoing pandemic and altered market conditions.

Another source of limitations is the use of energy prices from the publicly available sources and for a particular time period. Those prices will change over time and some, for example wood pellet or coal prices, will vary with respect to fuel quality which is ultimately decided by the homeowner. Homeowner choices of the heating energy type will influence the volume of GHG emissions, but will not reverse the general trend in emission reduction due to the shift away from using coal.

The current study did not account for the cost of the parcel, which is likely to be highly variable across rural areas in the country. A closer examination of household incomes and construction costs will enable the forecasting of new house construction, and potentially, regional economic growth and real estate market development. Earlier studies linked the energy performance of dwellings with market valuation [69,70] once the suitable data became available. Also, the scenarios presented in the current paper can be supplemented by financial analyses, which can account for regional household income variation and different types of mortgage loans. Finally, as new construction technology and heating systems become available, a future study will be necessary to update the data on energy savings and environmental benefits.

6. Conclusions

Improved energy-efficiency of single-family homes in Poland is required by the new building regulations, while the retrofitting of the existing detached houses is supported by government programs aiming at enhancing air quality as well as energy and climate policies. The energy demand reduction and environmental benefits occur primarily in rural areas because the detached houses dominate the rural landscape. Results from this study show that switching away from coal, still the primary energy sources in rural areas, required by new construction regulations leads to a substantial increase in construction costs of the shell of a house and even larger costs in installing the RE utilizing equipment to heat space and domestic water. The costs increase for a model single-family home considered here far exceed the previous estimates for other EU countries. The increased costs may deny the opportunity of residing in own home to many rural households due to debt servicing. However, retrofitting an existing house improving its energy-efficiency also generates substantial savings to households on their energy bill. Retrofitting split into smaller projects, as permitted by household savings, is realistic and likely to continue in rural areas.

The use of RE is required in all new detached housing, but encouraged in the existing single-family homes by the subsidy programs. The scenarios considered in this study used wood pellet, solar radiation

and geothermal energy. For rural households, the RE in the form of wood pellet may be more appealing because it can reliably heat the house, while being locally accessible. The intensity of solar radiation is inversely related to the heating energy needs of households in Poland determined by climate. The regional variations in climate will have to be considered by households investing in a new home since the winter temperatures can substantially vary. Regional considerations are often ignored in the “one-size-fits-all” regulations, and are verified by the actual site-specific conditions.

The environmental sustainability is well served by the new construction regulations and the scenarios considered in this study. Gains in reduction of CO₂ are impressive once a household uses any amount of RE in comparison to a traditional rural house the uses coal. Retrofitting the existing house with the wood pellet burning boiler nearly eliminates CO₂ and SO₂ emissions, while substantially lowers other noxious gases and particulate matter. The effects are instantaneous in improving local air quality, while the broader effects benefit the implementation of the decarbonization efforts and help achieve goals of the climate policy.

Author Contributions: Conceptualization: A.S. and A.M.K.; Data curation: A.S.; Formal analysis: A.S.; Investigation: A.S., A.M.K. and W.J.F.; Methodology: A.S., A.M.K. and W.J.F.; Supervision: A.M.K.; Writing—original draft: A.S., A.M.K. and W.J.F.; Writing—review & editing: A.S., A.M.K., W.J.F., P.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Construction materials used in the various scenarios were selected by the architectural design firm Archiko, Kornelia Lisowska-Siudek, Manager, and the labor costs were estimated by the construction company collaborating with the design firm. Construction cost estimates were also based on the estimations developed by the company, “Dobredomy”.

Appendix B

Table A1. Annual heating energy needs, energy production costs, auxiliary electricity needs and total costs for a rural detached residence central heating system.

Cost Category	Units	Traditional House (Coal)	Traditional House (Natural Gas)	Traditional House (Wood Pellet)	Energy-Saving House (Natural Gas + Solar Panels)	Energy-Neutral House (Heat Pump + PV)
Heating energy	kWh/year	31,909	19,923	27,350	5300	4481
Price per kWh from a given heat source	PLN	0.13	0.25	0.21	0.12	0.12
Energy production costs	PLN	4148	4981	5744	636	538
Auxiliary electrical power supply	kWh/year	334	363	179	351	351
Price per kWh ^a	PLN	0.65	0.65	0.65	0.65	0.65
Energy production costs	PLN	255	234	116	228	228
Total costs	PLN/EUR	4404/1039	5217/1219	5860/1369	864/202	766/179

Source: Based prices listed by [71] and data from [16]. ^a Price from [16].

Table A2. Energy generation costs for the domestic water heating system.

Cost Category	Units	Traditional House (Coal)	Traditional House (Natural Gas)	Traditional House (Wood Pellet)	Energy-Saving House	Energy-Neutral House
Heat demand	kWh/year	29,396	14,409	23,706	14,409	4105.5
Price 1kWh from a given heat source	PLN	0.13	0.25	0.21	0.25	0
Cost of Energy production	PLN	3821	3602	4978	3602	0
Auxiliary electrical power supply	kWh/year	169	272	215	272	247
Price for 1 kWh of (GUS, 2016)	PLN	0.65	0.65	0.65	0.65	0.65
Energy production costs	PLN	110	177	140	177	161
Total costs	PLN/EUR	4007/936	3779/883	5118/1196	3779/883	148/34

Source: Calculations based on company price list [71], and data from [16].

References

1. Gawlikowska-Fyk, A. Coping with the challenges of decarbonization and diversification. In *New Political Economy of Energy in Europe*; International Political Economy Series; Palgrave Macmillan: London, UK, 2018; pp. 195–2014.
2. European Commission National Energy and Climate Plans. Executive Summary of Poland's National Energy and Climate Plan for the Years 2021–2030. 2020. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/pl_final_necp_summary_en.pdf (accessed on 28 September 2020).
3. KOBIZE. Wartości Opałowe (WO) i Wskaźniki Emisji CO₂ (WE) w Roku 2015 do Raportowania w Ramach Systemu Handlu Uprawnieniami do Emisji za Rok 2018; KOBIZE: Warszawa, Poland, 2017.
4. Emissions (Metric Tons per Capita)—Poland. 2020. Available online: <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=PL> (accessed on 27 October 2020).
5. Canales, F.A.; Jadwiszczak, P.; Jurasz, J.; Wdowikowski, M.; Ciapała, B.; Kaźmierczak, B. The impact of long-term changes in air temperature on renewable energy in Poland. *Sci. Total Environ.* **2020**, *729*. [CrossRef] [PubMed]
6. Czyż Polacy Ogrzewają Domy? Najnowsze Dane GUS. 2019. Available online: <https://www.gramwzielone.pl/trendy/102011/czym-polacy-ogrzewaja-domy-najnowsze-dane-gus> (accessed on 22 October 2020).
7. Kamińska, W.; Heffner, K. *Polityka Spójności UE a Rozwój Obszarów Wiejskich. Stare Problemy i Nowe Wyzwania*; KPZK PAN: Warszawa, Poland, 2014; pp. 267–282.
8. Klepacka, A.M.; Florkowski, W.J.; Meng, T. Clean, Accessible, and Cost-Saving: Reasons for Rural Household Investment in Solar Panels in Poland. *Resour. Conserv. Recy.* **2018**, *139*, 338–350. [CrossRef]
9. Część Druga Programu dla Beneficjentów Uprawnionych do Podwyższonego Poziomu Dofinansowania. Available online: <http://czystepowietrze.gov.pl/wez-dofinansowanie/> (accessed on 14 August 2020).

10. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency. Available online: <https://eur-lex.europa.eu/legal-content/pl/TXT/?uri=CELEX%3A32018L0844> (accessed on 27 October 2020).
11. Act of 13 February 2020 Amending the Act-Building Law and Certain Other Acts. Available online: <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20200000471> (accessed on 27 October 2020).
12. Gałązka, T. *Krajowy Plan Mający Na Celu Zwiększenie Liczby Budynków O Niskim Zużyciu Energii*; Wydawnictwa Uczelniane UTP w Bydgoszczy: Bydgoszcz, Poland, 2015.
13. Kundzewicz, Z.W.; Matczak, P. Climate change regional review: Poland. *Wires Clim. Chang.* **2012**, *3*, 297–311. [CrossRef]
14. Eurostat. GDP per Capita in PPS. 2020. Available online: <https://ec.europa.eu/eurostat/databrowser/view/tec00114/default/table?lang=en> (accessed on 23 October 2020).
15. Capros, P.; Paroussos, L.; Fragkos, P.; Tsani, S.; Boitier, B.; Wagner, F.; Busch, S.; Resch, G.; Blesl, M.; Bollen, J. European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis. *Energy Strateg. Rev.* **2014**, *2*, 231–245. [CrossRef]
16. GUS. *Zużycie Energii w Gospodarstwach Domowych w 2018 Roku*; GUS: Warszawa, Poland, 2019.
17. Porozumienie Branżowe na Rzecz Efektywności Energetycznej POBE. Jak Spełnić Wymagania, jakim Powinny Odpowiadać Budynki od 2021 Roku? *Poradnik dla Architektów, Projektantów i Inwestorów*. Available online: https://www.nibe.pl/Documents/nibe_pl/12_Poradnik_POBE_WT_2021_jak_spelnic_wymagania.pdf (accessed on 14 August 2020).
18. Grudzińska, M.; Jakusik, E. Energy performance of buildings in Poland on the basis of different climatic data. *Indoor Built Environ.* **2017**, *26*, 561–566. [CrossRef]
19. Krawczyk, D.A. International Scientific Conference “Environmental and Climate Technologies”, CONECT 2015, 14–16 October 2015, Riga, Latvia Analysis of energy consumption for heating in a residential house in Poland. *Energy Procedia* **2015**, *95*, 216–222. [CrossRef]
20. Pater, S. Field measurements and energy performance analysis of renewable energy source devices in a heating and cooling system in a residential building in southern Poland. *Energy Build.* **2019**, *199*, 115–125. [CrossRef]
21. Pantoutsou, C.; Bauen, A.; Böttcher, H.; Alexopoulou, E.; Fritsche, U.; Uslu, A.; van Stralen, J.N.P.; Elbersen, B.; Kretschmer, B.; Capros, P.; et al. Biomass futures: An integrated approach for estimating the future contribution of biomass value chains to the European energy system and inform future policy formation. *Biofuel Bioporducts Biorefin.* **2013**, *7*, 106–114. [CrossRef]
22. European Commission. *Energy Road Map 2050*; Publications Office of the European Union: Luxembourg, 2012.
23. Mocny Trend. Polacy Przeprowadzają się do Domów i Szeregowców. 2017. Available online: <https://tvn24.pl/biznes/z-kraju/gus-spada-ilosc-gospodarstw-domowych-w-domach-wielorodzinnych-ra775548-4486182> (accessed on 26 October 2020).
24. Bauermann, K. German Energiewende and the heating market—Impact and limits of policy. *Energy Policy* **2016**, *94*, 235–246. [CrossRef]
25. Del Río, P.; Burguillos, M. An empirical analysis of the impact of renewable energy deployment on the local sustainability. *Renew. Sust. Energ. Rev.* **2009**, *13*, 1314–1325. [CrossRef]
26. Moula, M.M.E.; Maula, J.; Hamdy, M.; Fang, T.; Jung, N.; Lahdelma, R. Researching social acceptability of renewable energy technologies in Finland. *Int. J. Sustain. Built Environ.* **2013**, *2*, 89–98. [CrossRef]
27. Bertsch, V.; Hall, M.; Weinhardt, C.; Fichtner, W. Public acceptance and preferences related to renewable energy and grid expansion policy: Empirical insights from Germany. *Energy* **2016**, *114*, 465–477. [CrossRef]
28. GUS. *Obszary Wiejskie w Polsce w 2018 Roku*; GUS: Warszawa, Poland, 2020.
29. GUS. *Zużycie Energii w Gospodarstwach Domowych w 2015 r*; GUS: Warszawa, Poland, 2017.
30. Bochnia, K. Budynki Niemal Zeroenergetyczne. *Builder* **2017**, *65*, 64–65.
31. Tomsej, T.; Horak, J.; Tomsejova, S.; Krpec, K.; Klanova, J.; Dej, M.; Hopan, F. The impact of co-combustion of polyethylene plastics and wood in a small residential boiler on emissions of gaseous pollutants, particulate matter, PAHs and 1,3,5-triphenylbenzene. *Chemosphere* **2018**, *196*, 18–24. [CrossRef] [PubMed]
32. Stecuła, K.; Tutak, M. Causes and effects of low-stack emission in selected regions of Poland. 18th International Multidisciplinary Scientific Geo-Conference SGEM 2018. *Sect. Air Pollut. Clim. Chang.* **2018**, *18*, 357–364. [CrossRef]

33. Krause, P.; Steidl, T.; Wojewódka, D. Kierunki Termomodernizacji. *Builder* **2015**, *46*, 46–48.
34. Dziennik Ustaw. Minister of Transportation, Construction and Maritime Regulation of 5 July 2013, Regarding the Technical Conditions Pertaining to Buildings and Their Location. Item 926, August 2013. Available online: <http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20130000926> (accessed on 30 April 2020).
35. Dziennik Ustaw. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z Dnia 7 Czerwca 2018 r. w Sprawie Ogłoszenia Jednolitego Tekstu Ustawy-Prawo Budowlane. Item 1202. 2018. Available online: <http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180001202> (accessed on 8 September 2020).
36. GUS. *Zamieszkane Budynki. Narodowy Spis Powszechny Ludności i Mieszkań w 2011*; GUS: Warszawa, Poland, 2013.
37. GUS. *Budownictwo w 2020 Roku*; GUS: Warszawa, Poland, 2020.
38. Dziennik Ustaw. Minister of Infrastructure and Development Regulation of 27 February 2015, Regards the Methodology of Determining Energy Features of Buildings and Buildings Parts and Building Features certification. Item 376, 18 March 2015. Available online: <http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20150000376/O/D20150376.pdf> (accessed on 10 November 2020).
39. Krochmal, D.; Kalina, A. Measurements of nitrogen dioxide and sulphur dioxide concentrations in urban and rural areas of Poland using passive sampling method. *Environ. Pollut.* **1997**, *96*, 401–407. [[CrossRef](#)]
40. Hławiczka, S.; Kubica, K.; Zielonka, U. Partitioning factor of mercury during coal combustion in low capacity domestic heating units. *Sci. Total Environ.* **2003**, *302*, 261–265. [[CrossRef](#)]
41. Tainio, M.; Juda-Rezler, K.; Reizer, M.; Warchałowski, A.; Trapp, W.; Skotak, K. Future climate and adverse health effects caused by fine particulate matter air pollution: Case study for Poland. *Reg. Environ. Chang.* **2013**, *13*, 705–715. [[CrossRef](#)]
42. Jędrak, J.; Konduracka, E.; Badyda, A.J.; Dąbrowiecki, P. *Influence of air pollution on health. Polskiego Towarzystwa Medycyny Środowiskowej, Wojskowego Instytutu Medycznego, Polskiej Federacji Stowarzyszeń Chorych na Astmę, Alergię i POChP*; Krakowski Alarm Smogowy: Krakow, Poland, 2017; ISBN 978-83-943065-0-2.
43. Wang, Q.; Xu, X.; Zeng, Z.; Zheng, X.; Ye, K.; Huo, X. Antioxidant alterations link polycyclic aromatic hydrocarbons to blood pressure in children. *Sci. Total Environ.* **2020**, 732. [[CrossRef](#)]
44. Kalkulator Budowlany-Cennik Płyt Fundamentowych 2020 w Ponad 150 Miastach w Polsce. Available online: <https://kb.pl/cenniki/plyta-fundamentowa/> (accessed on 15 November 2020).
45. Kalkulator Budowlany-Styropian EPS czy Styropian XPS? A Może Gwarantowy? Available online: <https://kb.pl/porady/styropian-eps-czy-styropian-xps-moze-gwarantowy-sprawdzamy/> (accessed on 15 November 2020).
46. Retail Price List of Blachotrapez. Available online: https://www.blachotrapez.eu/pl/pliki/cennik-detaliczny-blachotrapez?gclid=Cj0KCQiAnb79BRDgARIsAOVbhRpeXyhqgmnfefqFBiWhrlcKc4hLyg4yJvmlL3V2gzxgNxoQrv7UpzvMaAuS7EALw_wcB (accessed on 15 November 2020).
47. Budujemy Dom-Dach Kryty Dachówką Ceramiczna Przykładowa Wycena. Available online: <https://budujemydom.pl/stan-surowy/dachy-i-rynny/a/17293-dach-kryty-dachowka-ceramiczna-przykladowa-wycena> (accessed on 12 November 2020).
48. Kalkulator Budowlany-Okna Trzyszybowe czy Dwuszybowe-Porady i Ceny. Available online: <https://kb.pl/porady/okna-trzyszybowe-czy-dwuszybowe-porady-i-ceny-dla-kazdego/> (accessed on 10 November 2020).
49. Kalkulator Budowlany-Montaż Drzwi- Cennik po Województwach. Available online: <https://kb.pl/porady/montaz-drzwi-cennik-po-wojewodztwach/> (accessed on 9 November 2020).
50. Kalkulator Budowlany-Cennik Ocieplenia Poddasza Użytkowego 2020 w Ponad 150 Miastach w Polsce. Available online: <https://kb.pl/cenniki/ocieplenie-poddasza-uzytkowego/> (accessed on 10 November 2020).
51. Available online: <https://www.hurtowniastyropianu.pl/sklep/styropian/plyty-pir/> (accessed on 10 November 2020).
52. Strop Monolityczny-Ile Kosztuje? *Aktualne Ceny i Charakterystyka*. Available online: <https://jakbudowac.pl/Strop-monolityczny-ile-kosztuje-Aktualne-ceny-i-charakterystyka> (accessed on 10 November 2020).
53. Koszty Różnych Rodzajów Kominów. Available online: <https://www.instalacjebudowlane.pl/6533-23-12396-koszty-roznych-rodzajow-kominow.html> (accessed on 10 November 2020).
54. Strona Internetowa Firmy Regulus Wraz z Cennikami. Available online: <https://www.regulus.com.pl/news/grzejniki-niskotemperaturowe> (accessed on 13 November 2020).
55. Wentylacja Grawitacyjna- co to Jest i Ile Kosztuje? Available online: <https://wentylacja.com.pl/news/wentylacja-grawitacyjna-co-to-jest-i-ile-kosztuje-67245.html> (accessed on 10 November 2020).

56. Wentylacja Grawitacyjna czy Mechaniczna? Available online: <https://www.rekuperatory.pl/wentylacja-grawitacyjna-czy-mechaniczna> (accessed on 13 November 2020).
57. Kalkulator budowlany-Koszt Budowy Domu 2020- Wylczenia Krok po Kroku. Available online: <https://kb.pl/porady/koszt-budowy-domu-dokladne-wylczenia/> (accessed on 12 November 2020).
58. Lorenc, H. *Atlas Klimatyczny Polski*; Instytut Meteorologii i Gospodarki Wodnej: Warszawa, Poland, 2005.
59. NBP. Tabela A kursów Średnich Walut Obcych. Tabela nr 221/A/NBP/2019 z Dnia 2019-11-15. 2020. Available online: <http://rss.nbp.pl/kursy/TabRss.aspx?n=2019/a/19a221> (accessed on 15 November 2020).
60. Park, N.D.; Rutherford, P.M.; Thring, R.W.; Helle, S.S. Wood pellet fly ash and bottom ash as an effective liming agent and nutrient source for rye grass (*Lolium perenne* L.) and oats (*Avena sativa*). *Chemosphere* **2012**, *86*, 427–432. [CrossRef] [PubMed]
61. Kerimray, A.; Rojas-Solorzano, L.; Torkmahalleh, M.A.; Hopke, P.H.; O Gallachoir, B.P. Coal use for residential heating: Patterns, health implications and lessons learned. *Energy Sustain. Dev.* **2017**, *40*, 19–30. [CrossRef]
62. Petersen Raymer, A.K. A comparison of avoided greenhouse gas emissions when using different kinds of woody energy. *Biomass Bioenerg.* **2006**, *30*, 605–617. [CrossRef]
63. Michalska, M.; Zorena, K.; Waz, P.; Bartoszewicz, M.; Brandt-Varma, A.; Slezak, D.; Robakowska, M. Gaseous pollutant and particulate matter in ambient air and the number of new cases of Type 1 diabetes in children and adolescents in the Pomeranian Voivodeship, Poland. *Biomed Res. Int.* **2020**. [CrossRef]
64. Właściwości Paliwa. 2020. Available online: <http://www.pelet.info.pl/x.php/1,439/Wlasciwosci-paliwa.htm> (accessed on 19 November 2020).
65. Available online: <https://vaillant-partner.pl/kalkulatory-on-line/kalkulator-emisji-zanieczyszczen/> (accessed on 19 November 2020).
66. Audenaert, A.; De Cleyn, S.H.; Vanckerkhove, B. Economic analysis of passive houses and low-energy houses compared with standard houses. *Energy Policy* **2008**, *36*, 47–55. [CrossRef]
67. Schnieders, J.; Hemerlink, A. CEPHEUS results: Measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. *Energy Policy* **2006**, *34*, 151–171. [CrossRef]
68. Szopiński, T. Kontrowersje wokół “walutowych” kredytów hipotecznych. *Konsumpcja Rozw.* **2018**, *22*, 79–84.
69. Manganelli, B.; Morano, P.; Tajani, F.; Salvo, F. Affordability assessment of energy-efficient building construction in Italy. *Sustainability* **2019**, *11*, 249. [CrossRef]
70. De Ruggiero, M.; Forestiero, G.; Manganelli, B.; Salvo, F. Buildings energy performance in a market comparison approach. *Buildings* **2017**, *7*, 16. [CrossRef]
71. Cennik Firmy Viessmann. 2020. Available online: <https://www.broetje.pl/wp-content/uploads/2017/04/Cennik-Brotje-2019-wydrukowany.pdf> (accessed on 24 October 2020).

Publisher’s Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).