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# Energy Innovation for Individual Consumers in Poland—Analysis of Potential and Evaluation of Practical Applications in Selected Areas

**Ewa Chomać-Pierzecka [1,*], Joanna Rogozińska-Mitrut [2], Monika Różycka [3], Dariusz Soboń [4] and Jacek Stasiak [5]**

[1] Faculty of Economics, Jacob of Paradies Academy in Gorzów Wielkopolski, 66-400 Gorzów Wielkopolski, Poland
[2] Faculty of Economics, Pomeranian University in Słupsk, 76-200 Słupsk, Poland; joanna_rogozinska@wp.pl
[3] Faculty of Economics, Finance and Management, University of Szczecin, 70-453 Szczecin, Poland; monika.rozycka@usz.edu.pl
[4] WSB Merito in Warszawa, 03-204 Warszawa, Poland; sj@list.pl
[5] Non-Public Health Care Centre Interschool Department of Rehabilitation and Correction Science and Research Center, 95-070 Aleksandrów Łódzki, Poland; jacek_stasiak@interia.pl
* Correspondence: echomac-pierzecka@ajp.edu.pl

**Abstract:** Green technologies are undergoing strong development. These are created by global formal and legal regulations enforcing the reduction of the share of non-renewable energy sources in the energy systems of economies and the minimisation of harmful emissions through the development of technologies based on renewable energy sources. In addition, the development of green technologies is driven by the need to reduce the rising cost of electricity, particularly affecting households in countries heavily reliant on coal-fired power generation, where green technologies are only just gaining popularity (e.g., Poland). With this in mind, it was considered important to present the formal and legal background of the development of the Polish energy system towards sustainability and to discuss the green technology market in Poland, including innovative solutions in this field, which are or could be, applied to small individual consumers (households). The main objective of the study was to analyse the interest of households in innovative green technology solutions, determined by the surface area and cubic capacity of buildings, in order to strengthen the source material that can be used by decision-makers when designing a strategy for the development of the green energy market in Poland, with a special focus on individual consumers. The study was carried out based on a critical analysis of the available literature, regulations, and industry reports, as well as survey material enabling practical evaluation of solutions by users of innovative technologies. The practical research dimension was reinforced by statistical instrumentation, using the statistical instrument PQstat version 1.8.4.164. The main findings of this study show a significant level of openness of households in Poland to innovative green technologies and a clear relationship between the area and volume of a building and the range of choices made. The most popular solutions in this respect include photovoltaics, followed by heat pumps. Furthermore, it was noted that the area and cubic volume of a building determines the potential and scale of future strengthening of the RES dimension by small individual consumers.

**Keywords:** green growth; green innovation; renewable energy management; renewable energy economics; green technologies for small consumers



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## 1. Introduction

Increasing socio-economic demands need the creation of novelty. Hence the search for innovative solutions to improve several spheres of life is a key aspect of contemporary economic development and the leading driving force behind civilisational development. Socio-economic requirements determining innovativeness arise against the background of

improving quality and safety of functioning, while quality most often refers to improved, distinctive features characterising a solution, most often concerning utility values (deepening comfort of use, increasing functionality, increasing efficiency, etc.), maximising safety, on the other hand, concerns the spheres of

- Manufacturing (in relation to the internal and external environment of the company),
- The use of the product (in relation to its composition, construction, or performance characteristics),
- Social accessibility of solutions correlated with the economic aspect.

The improvement of basic solutions and the search for new alternatives particularly concerns the energy market. Several considerations lead to this. The main one is the environmental policy exposed in the countries of Europe and the world, aimed at limiting the consumption of natural resources, whose non-renewable nature emphasises their limited nature, as well as minimising the negative impact of energy production on the environment, by limiting discharges and emissions of harmful substances, which are a derivative of conventional production methods. The environmental aspect can be regarded as a classic motivator for efforts to find innovative, environmentally-safe solutions in the energy industry.

Another dimension of the orientation towards innovation in the energy sphere grows out of the economic background. The increase in prices of increasingly scarce non-renewable resources, as well as the increase in environmental charges due to the negative impact of traditional energy production on the natural environment, have, in a relatively short period, created a serious increase in energy purchase prices on the market. This is particularly true for countries heavily dependent on coal for energy production, which includes Poland. The reality of rising energy purchase prices has shaped a strong need to reach for solutions offering innovative generation alternatives based on renewable energy sources. The economic aspect, supported by action to protect the natural environment, makes this direction obvious and justified. Hence the need to enrich the range of available innovative solutions in this sphere constitutes a very strong motivation to make efforts to improve existing solutions and work on new dimensions of innovation in this field.

The disruption to the existing order of raw material supply of energy production using fossil fuels due to the outbreak of war in Ukraine has reinforced the observed trend of efforts to strengthen the share of renewable energy sources (RES) in the energy production of individual economies. The aspect of energy security-shaken by the strongly limited availability of raw materials for energy production and economic security—due to the very high cost of acquiring raw materials for energy production sourced from the parties to the ongoing armed conflict—are important determinants of the orientation towards technological innovation, due to the need to remodel the temporal energy supply systems. Innovative—at the level of economies, solutions have gained popularity, and the demand to improve the spectrum of their practical application has triggered a range of research and work on new and novel challenges. The exploration of these aspects within the framework of a scientific reconnaissance constitutes the study's timeliness, validity, and, at the same time, originality.

Innovative green technology solutions are dedicated to different audiences, the strongest of which are institutional customers. An important aspect of changes taking place in the energy systems of economies is the public opinion approving or disapproving of the direction being pursued. A strong expression of the social stance towards the actions taken is the assessment of the popularity of innovative solutions, considered through the prism of interest in innovative solutions for energy generation, expressed at the household level. Therefore, the main objective of the study is to analyse the interest of households in Poland in renewable energy solutions for this group of consumers and to assess the potential for practical choices in this area. The proposed issue is strengthened by the relatively limited number of current studies in this field, especially at the level of the country adopted for the research (Poland), which determined the choice of the subject and scope of the research. The above makes the article up-to-date and original, creating an answer to the identified

research gap in the explored scope. Importantly, the research gap in the sphere of RES solutions targeted at individual consumers in Poland is strongly articulated in the literature, strengthening the present study's significance. Hence, the proposed research issue was considered an important topic in the current economic reality (armed conflict in Ukraine), in which the need to reach for solutions secure in terms of the availability of energy supply and the price of its acquisition is particularly important. The added value is created by the overall objective of the study, related to the review of the formal and legal framework determining the development of the Polish energy system towards sustainability.

## 2. Materials and Methods

The purpose of the study shaped its layout. The introduction took on a conceptual character. An in-depth analysis of the research background was captured in the literature review, which included research literature, statistical data, reports, and industry studies. Literature was drawn from open-access databases.

The empirical and analytical part was conducted using the rules of economic analysis, allowing for a correct diagnosis of the state, correct decomposition and systematisation of phenomena for a factual formulation of conclusions. Figure 1 shows the research concept adopted.

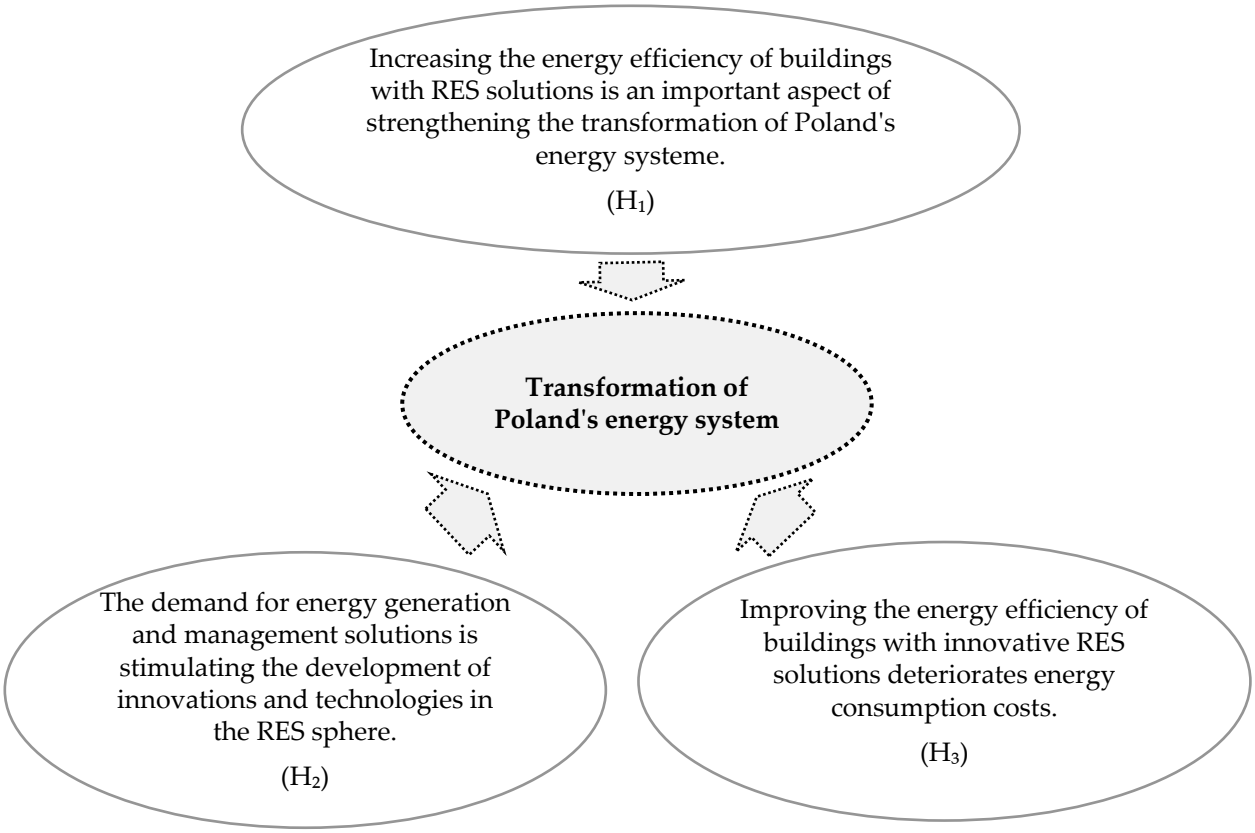


**Figure 1.** Research concept.

The model adopted was created based on research assumptions captured in the hypotheses formulated:

**H1.** *Increasing the energy efficiency of buildings with RES solutions is an important aspect of strengthening the transformation of Poland's energy system,*

whereby (sub-hypotheses):

**H1.1.** *photovoltaic installations contribute to strengthening the energy system of Poland,*

**H1.2.** *heat pump installations contribute to strengthening the energy system of Poland,*

**$H_{1.3.}$** *other installations of the RES area (solar installations, small wind installations) contribute to the strengthening of the energy system of Poland.*

**$H_{2.}$** *The demand for energy harvesting and management solutions stimulates the development of innovations and technologies in the RES sphere.*

**$H_{3.}$** *Increasing the energy efficiency of buildings with innovative RES solutions determines the reduction of energy consumption costs.*

For detailed statistical research, 3 sub-hypotheses were adopted, derived from the main hypothesis.

The development of solutions based on renewable energy sources is an important aspect of the transformation of the energy systems of the world's economies. Thus, the study of the impact of this dimension of activities on the energy market is fully justified. The system of relations between increasing the energy efficiency of buildings and the application of the RES dimension in the Polish market requires in-depth recognition to develop solutions tailored to current expectations that support the trend in question. Taking up the research challenge oriented towards the identification of cause-and-effect relationships in this area on the ground of households should therefore be considered important and timely. The analytical material for this part of the study was obtained from a review of requests for proposals and offers for the implementation of installations in the area of RES, juxtaposed with the practical choices of customers in the period 2021–2022 of one of the companies involved in the design of heating installations and intermediation in the sale and installation of equipment from the RES sphere, with an established position on the Polish market in the Lubuskie, Zachodniopomorskie and Wielkopolskie Voivodeships. The questionnaire is an integral part of the service documentation completed during the service visit. The research area was reinforced by the results of a customer survey carried out by the company in question in connection with the implementation of the after-sales care process. In this area corresponding to the research problem, attention was focused on 3 questions from the diagnostic survey, which concerned:

- Evaluation of satisfaction with the use of solutions based on RES sources (closed question),
- Diagnosis of potential for further investments in RES solutions (investment direction-open question),
- The scope of investment potential-investment parameters, planned connection capacity, planned completion date, interest in financing, etc. (open scope).

Other questions of the questionnaire were complex and concerned the survey of satisfaction with the quality of services provided by the company. All the material obtained for the study assumed an anonymous character. It provided the basis for an assessment of consumer practice, an analysis of satisfaction with RES solutions obtained and an assessment of the potential for further investment in RES by individual customers. It is worth noting here that the customer satisfaction survey of the company in question assumes a continuous character. For the analysis carried out in January 2023, surveys for the years 2021–2022 (January 2021–December 2022) were adopted, which included a sample of 143 customers (contracts), as well as the potential of customers expressed in the number of requests for proposals of 311, in response to which offers were made in the field of RES solutions. The analytical material obtained during this study for this article has been used in the requested part, and further dimensions will be used for further research—according to the authors' assumptions.

The concept presented determined the following layout of the research:

1. Introduction,
2. A review of the literature on the energy market in order to make a general assessment of the trends of change taking place, as an introduction to the problems of the article.
3. The analysis of the green technology market in Poland, taking into account innovative solutions in this field, which are or could be applied to small individual consumers (households), and the analysis of interest in innovative green technology solutions

by households, together with the assessment of economic effects of such action. This part of the research was conducted based on offers, contracts and questionnaires from customers of a company dealing with the sale and installation of installations in the field of renewable energy in Poland, in the Lubuskie, Wielkopolskie and Zachodniopomorskie voivodships,

4. Discussion,
5. Summary and conclusions.

The main goal of the Authors specified for the conducted research is to strengthen the knowledge in the field of development of innovative energy technologies in RES, with particular consideration of individual customers in Poland, as the purchasing potential of energy obtained in this way. The above will contribute to an informative area of research, which can provide input data for analysis and modelling of the development strategy of the renewable energy market in Poland. Hence the topic was considered important.

## 3. Innovation in the Energy Market in the Light of Changing Trends—A Literature Review

Environmental protection has become the domain of the functioning and development of modern civilisation. The limitation of natural resources and their overexploitation [1] has contributed to an increase in the cost of their acquisition, creating a strong increase in the cost of production and, consequently, in the market price of a number of goods [2]. Hence, the economic rationale has become the search for production alternatives, prompting innovation.

Excessive interference in the environment, e.g., in connection with the extraction of natural resources and their processing emitting toxins into the air, as well as the discharge of harmful substances into water or soil, has had a strong impact on ecosystems, disrupting their functioning and, in extreme cases, contributing to their successive extinction [3]. At a global level, mankind has been affected by the destruction of the earth's planet, the aftermath of which is increasing climate change with a range of negative consequences affecting the world. A transformation of countries' existing energy systems has become more than justified and urgent. Reaching for innovation in this sphere has begun to gain popularity. The social and behavioural context of energy systems modelling [4]—fraught with several challenges [5]—has begun to change. Hence, the economic considerations of modern economics were complemented by the environmental aspect, determined by concern for the planet, providing a strong motivation to take action to reduce environmental intrusion [6] and increase resource efficiency and process effectiveness. The need to improve solutions [7] and their orientation towards renewable energy sources began to be understood and increasingly accepted. Efforts were focused on finding innovative solutions in which all the above-mentioned factors became a basic expectation. The modern economy began to be oriented towards social responsibility, in which concern for people and their current expectations are not in conflict with care for nature [8]. This is an extremely important trend, as the backbone of the functioning of modern economies is driven by the energy sector. Hence it is assumed that the development of this field is a determinant of the development of modern economies [9,10]. In response to the above, ensuring access to cheap, clean energy has become a leitmotif in the search for solutions that meet contemporary expectations [11]—including in the sphere of modelling the right relationship between commercial and social implications and environmental policy. This has created a set of challenges for research and development, the main aim of which is to drive the transformation of the world's energy system through the improvement of existing solutions (decarbonisation, efficiency improvement, etc.) and, above all, the creation of new technical and technological approaches in the energy sphere [12], oriented towards drawing on RES. Importantly, innovative activities in this field are ultimately aimed at solving social problems (ensuring energy security affordably and responsibly), which gives them particular importance. In this light-referring to the considerations of N. Bergman et al. on the definition of innovation, technical and technological innovation in the field of energy can be described as innovation with a social dimension [13]. New ideas oriented

towards the mode of sustainable decision-making, the choice of a green energy source, or support for the idea of decarbonisation of activities can be considered as the result of the action of ideas (innovations) oriented towards the achievement of social goals [14]. In this respect, ideas shape the concepts of innovative energy production and storage systems, together with solutions that make these solutions smart [14].

P. Jiang et al. point out that innovation activities in this sphere are undergoing strong development, as evidenced by increasing public investment in this area, resulting in the market implementation of new energy solutions [15]. A. Rhodes et al. note that the directions of the contemporary orientation of innovative struggles are broadly forward-looking, focusing efforts on a proactive approach in product life cycle modelling [16]. R. Aydin et al., in turn, supplement the above with the theme of the need to include indicators from the area of sustainable development in this activity [17].

The process of creating a contemporary expected bundle of values for the benefit of its recipients must balance social and economic, as well as environmental aspects [18] (environmental well-being) [19]. At the same time, it is important to ensure that temporal development does not limit such opportunities for future generations [20]. In the context outlined, innovative activity in the energy sector should be seen as an evolutionary process that, based on research and development, provides new solutions and creates new possibilities for energy generation and distribution.

## 4. Results

### *4.1. Energy Efficiency in the Sustainable Development of Poland*

Innovation can be understood as the motivation to search for and implement, on a practical basis, the results of R&D findings, including new assumptions, ideas and inventions [21], and these can include new or improved products or new or modernised manufacturing solutions [22]. In the field of energy, one of the themes shown in this thesis that creates a pattern of innovation challenges is increasing energy efficiency. Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services defines energy efficiency as a measure of the degree to which energy is used in economic activity, which can be captured in the relationship between the economic effects generated by activity and the volume of energy input to that activity [23]. The drive to optimise the ratio of energy input to economic output creates a set of challenges for innovation efforts. The guiding objective in this area is to minimise energy losses, directly translating into economic savings through lower consumption, and to reduce overall energy demand, to the benefit of the environment. The above most fully fits into the context of sustainable development, where energy efficiency determines benefits in the social, economic (economic) and environmental spheres. In the context outlined, this aspect of the research challenges enjoys the highest public approval [24] and market interest.

The increase in energy demand observed worldwide [25] can be met in significant part by solutions that enable the full and efficient use of the energy generated. In this respect, the role of energy innovation and the long-standing policy of promoting energy-saving technologies [26] is highlighted. This means that progressive development does not necessarily entail a proportional increase in energy demand, as indicated by specific energy efficiency measures [27]. This creates space for the creation of innovative solutions to optimise energy generation and management processes.

The efficiency of the Polish energy system is a key determinant of the ongoing transformation processes. According to the scenarios for the Polish energy sector in 2050, the key activities in this respect are to focus on: [28]

(a) Stimulation of energy efficiency, supported by a system of measures for its growth, within the realisation of the established goal,
(b) Promotion of the development of Combined Heat Power,
(c) Dissemination of the idea of energy efficiency, combined with active support for investment measures to increase energy efficiency,

(d) Implementing the principles of Demand Side Management,
(e) Strengthening the R&D dimension in the area of innovative technical and technological solutions, optimising energy intensity in all areas of its production and use.

Placing energy efficiency at the centre of the expected results in the sphere of transformation, as well as strengthening the awareness and position of the energy consumer in the energy market, is expected to contribute significantly to the achievement of sustainable development goals [29]. Therefore, energy consumers have the right to reliable information, as well as the right to produce and use energy for their own needs. The above provides a sense of independence (energy security), a real opportunity for conscious energy management that can create savings and contribute to environmental protection.

T. Skoczkowski et al. point out that the highest potential for efficient energy management has for years been located in the construction sector, taking into account production technology and the technical development of premises, as well as in the field of transport and energy itself [30]. The authors indicated a very significant problem of low energy efficiency in dwellings, directly related to the heating/walking aspect of dwellings [30]. The search for solutions to rationalise energy use, coupled with the search for generic alternatives to conventional energy production, can be regarded as fundamental challenges of contemporary innovation.

In response to the challenges of optimising energy efficiency, innovative concepts for the construction of innovative dwellings have been developed, such as:

(a) Green buildings [31–33]:
- As a rule, large-volume sustainable buildings-economical and comfortable to use, created and maintained in an environmentally friendly manner (eco-friendly over the entire life cycle of the building),
- With a high level of energy efficiency, drawing energy from renewable sources and managing its use intelligently (savings are estimated to be around 25% below the average for a given volume),
- With very good acoustic parameters, very good natural light, using ecological materials and recycled ones,
- Equipped with a significant proportion of biologically active areas (e.g., green terraces),

(b) Energy-efficient detached houses:
- Buildings with a compact body, designed mainly on a rectangular plan with a single or double-pitched roof to minimise heat loss,
- Buildings using highly insulating building materials,
- Buildings using renewable energy sources,

(c) Passive detached houses:
- Characterised by maximally airtight construction achieved through very good insulation and exclusion of thermal bridges (heat loss potential),
- Using renewable energy sources and mechanical ventilation with heat recovery.

Ever-changing standards for the energy performance of buildings defined by law are making new construction more environmentally friendly. Projects are being developed with a constructional orientation towards energy efficiency, using improved materials and innovative solutions with low heat transfer coefficients, which have a real impact on improving energy efficiency. This means that houses which are not typically energy-efficient or passive have some of the characteristics of passive houses.

Buildings and structures under construction, erected based on designs that are several or more years old, already require investors' initiative to adapt them to current norms or increase their parameters, making the building more energy-efficient. In this respect, the strongest efforts are being made towards the current or future installation of renewable energy sources.

The greatest challenge is posed by buildings and structures that were constructed before 2015, when energy certification on the market became mandatory, with a particular

focus on those constructed in the last century. These buildings require several measures, such as thermal insulation, modernisation of the heating and ventilation system or replacement of installations, to adapt to the new possibilities of benefiting from innovative, energy-efficient technologies.

Improving the energy efficiency of structures and buildings in Poland is still a significant challenge, although, as emphasised in the literature, Poland has made great progress in this area since 2000 [30]. Nevertheless, it should be noted that the process in question is a complex, long-term challenge driven by political, economic and social considerations. The policy of sustainable development and the resulting transformation of the energy sector in Poland is creating changes in legislation that facilitate the achievement of goals in this area. However, it is extremely important to raise public awareness of the need to be open to change and motivated by instruments of financial support for undertakings in this area. The above is realised through several in-formation campaigns and funding programmes, e.g., from the state budget for thermal insulation, as well as from the National Fund for Environmental Protection and Water Management, Regional Operational Programmes, Provincial Funds for Environmental Protection and Water Management, the Swiss Funds, and also from European Union funds (e.g., the Infrastructure and Environment Initiative).

### *4.2. Innovative Green Technology Solutions in Polish Households—Analysis of Potential and Evaluation of Practical Applications in Selected Areas*

The energy efficiency of buildings is considered a very important aspect of the decarbonisation of the world [31]. It is also the most appropriate direction to develop price reductions for electricity consumption and environmental protection. According to common measures, this goal is achieved in Poland mainly through thermo-modernisation of existing buildings and structures, orientation towards green, renewable energy and green construction.

Orientation towards renewable energy sources is an important aspect of sustainable development. On the one hand, it is an expression of responsibility, being part of the canon of living according to the idea of sustainable development, and on the other hand, it is connected to the economic motivation for this direction of change.

The increase in electricity prices in Poland is generally progressive; hence the aspect of minimising the cost of living for households centres around the interest in renewable energy sources.

The trend in electricity prices in Poland is taking a strong upward turn—Figure 2 [34,35].

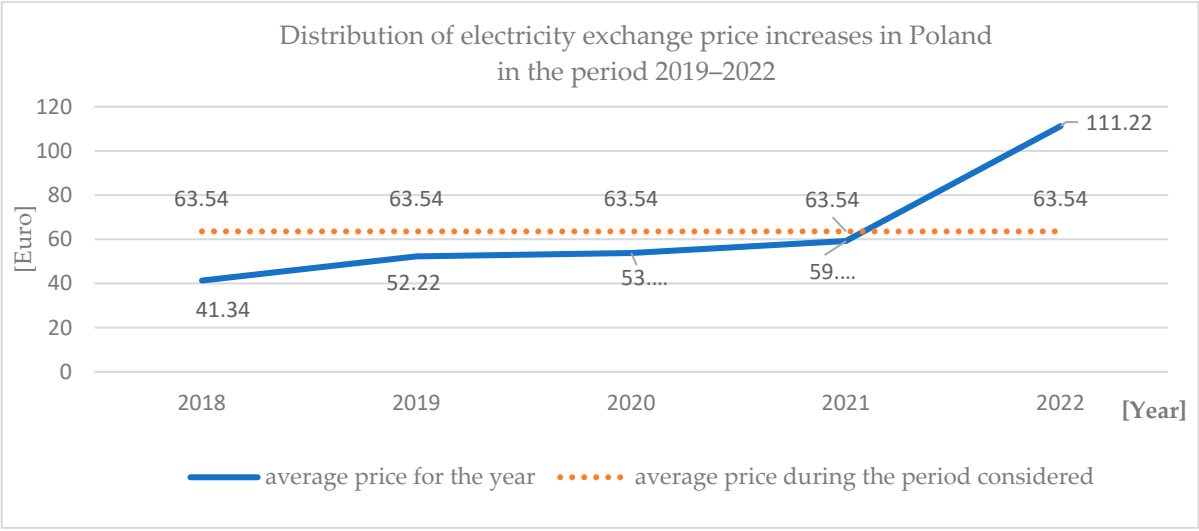


**Figure 2.** Distribution of electricity exchange price increases in Poland in the period 2019–2022.

Electricity prices on the wholesale market in Poland against the background of wholesale energy prices in the European Union oscillate around the average—Figure 3 [2,36,37].

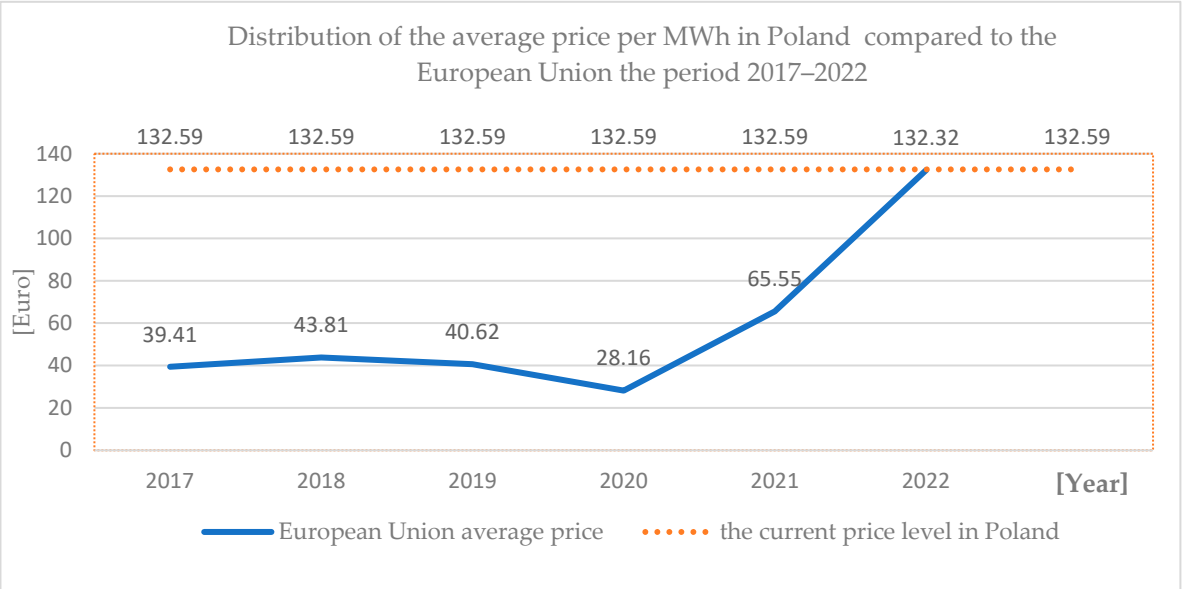


**Figure 3.** Distribution of the average per MWh compared to the European Union or the period 2017–2022.

Average prices in the competitive market in Poland compared to the European Union are below average—Figure 4 [38,39].

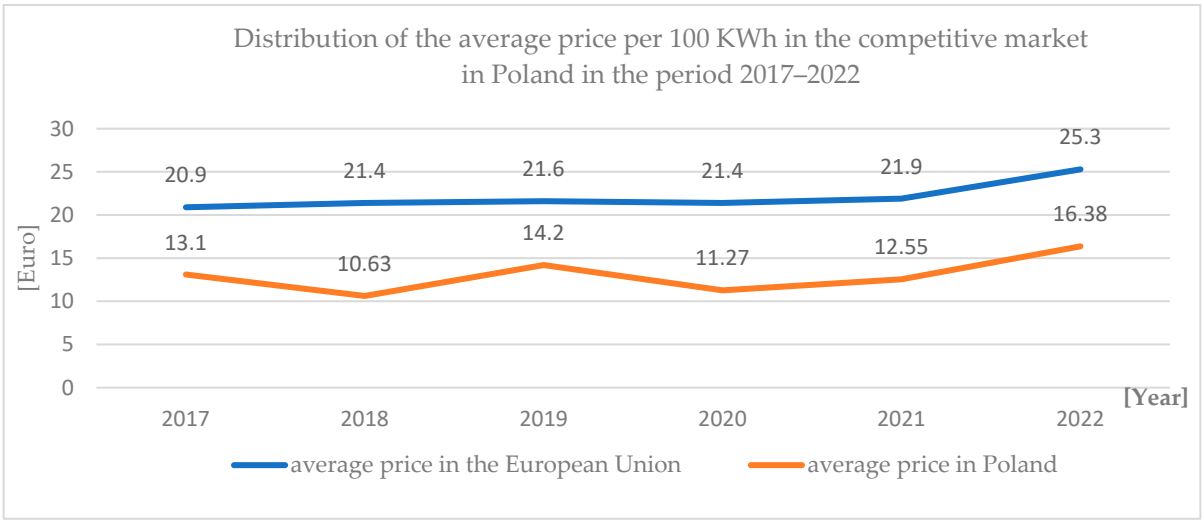


**Figure 4.** Distribution of the average price per 100 KWh in the competitive market in Poland in the period 2017–2022.

The relationship between the Polish currency and the euro makes the increase in electricity prices acute for Polish consumers. Hence, the increase in prices for the purchase of electricity is a strong incentive to open to new, innovative solutions, which, in addition to the opportunity to reduce electricity bills, can have a positive impact on the safety and comfort of life and the environment.

Solutions from the sphere of renewable energy sources enjoy recognition and interest among consumers in Poland. Investment choices in this field are focused on photovoltaics, heat pumps, as well as solar systems or micro wind installations. Confirmation in this respect is provided by the results of our research, which also indicate that all of the above-mentioned sources are considered, for the most part, as elements supporting the existing energy sources or as an alternative to the outdated forms of energy supply for buildings (modernisation of heating installations), as well as new solutions, often of an integrated

nature (2 or more heat sources). A detailed medium for this is the tender enquiries and contracts for the implementation of heating installations in the period 2021–2022 of one of the companies involved in designing installations and mediating in the sale and installation of equipment from the RES sphere, with an established position on the Polish market in the Lubuskie, Zachodniopomorskie and Wielkopolskie Voivodeships. The results of the research in the indicated area (small individual consumers) reveal that the main part of enquiries and contracts for RES solutions concerns facilities built during their construction or built in the past up to 5 years back (62%). An important part of the interest in the RES direction is represented by the modernisation of existing installations, related to the replacement of uneconomical and non-ecological heating boilers with new ones, with the additional provision of solutions from the RES sphere (34%). Plant reconstruction projects oriented fully towards RES solutions account for less than 4% of contracts and requests for proposals (total). Interestingly, a significant proportion of heating installations in houses in the process of being built, or built in the recent past, are oriented towards a combination of renewable and non-renewable, but low-carbon or renewable-low-carbon sources (78%). The main part of private investors (48%) invests in energy-efficient gas boilers combined with photovoltaic solutions or heat pumps. Importantly, photovoltaic-oriented solutions account for 62% of such choices, photovoltaic combined with heat pumps is 33% of the choices, with the remaining 5% being other combinations of photovoltaic, heat pumps, solar installations, or small wind installations. In the case of heat pump orientation, the primary choice is air pumps (93%) rather than the ground source. The main motivation for this choice is economical, related to the cost of the ground installation, which can be up to two or three times more expensive (cost of the pump, ground tests and boreholes), while technical considerations also play a role, related to the physical feasibility of such an installation (distance from the building, distance from planting, etc., due to ground frost). The own studies analysed also confirmed that a significant proportion of investors in the surveyed provinces in Poland choose to install ecological heating cookers using eco-pea coal (21%) or pellets (17%). The choice of low-emission sources also applies to ecological fireplaces (11%), including those using wood fuel (73%), pellets (14%) and gas (6%). Other solutions account for 3% and include high-efficiency cookers for different fuels and electric cookers. Electric cookers are also mentioned as an energy efficiency booster, with the option of drawing power from the grid or private energy banks. The latter are still very few in number due to the very high cost of acquiring them (around 4% of the solutions surveyed), with suggestions and further plans that this is a serious direction for the future orientation of small private investors.

A general discussion of the results of the questionnaires provides input to the detailed analysis that will enable answers to the established research problems to be developed. In this respect, a statistical analysis based on a logistic regression model was applied. The research strand was focused on analysing the impact of building area on the choice of RES solution. For the research, a division of the analysed buildings into two groups was adopted:

- With an area of up to 150 $m^2$,
- With a surface area of more than 150 $m^2$.

The main justification for the adopted division emerges from the financial aspect, related to the rate of taxation of installation services with a differentiated rate of Value Added Tax (VAT) in Poland, which amounts to 8% for facilities up to 150 $m^2$, while 23% for facilities of more than 150 $m^2$.

To verify the hypotheses, explanatory and explanatory variables were adopted. The conditions of transformation of the energy system in Poland, directly related to investments in RES to strengthen the energy efficiency of buildings, were adopted as explanatory variables. These variables were established in relate the analytical material covered by the study, adopting the range of sub-hypotheses:

$H_{1.1}$—photovoltaic installations contribute to strengthening Poland's energy system,

$H_{1.2}$—heat pump installations contribute to strengthening Poland's energy system,

$H_{1.3}$—other installations of the RES area (solar installations, small wind installations) contribute to the strengthening of the energy system of Poland.

The explanatory variables were related to the area of the building on a scale of 0–1, where 1 means the area of the building up to 150 $m^2$ and 0 means the area of the building above 150 $m^2$. The specification of the variables and their characteristics are included in Table 1.

**Table 1.** Specification of variables, together with their characteristics.

| Variable Number | Description Variable | Variable Designation | Type of Attribution |
|---|---|---|---|
| 1 | Selection of photovoltaic installations, strengthening Poland's energy system, | $X_1$ | Dichotomic |
| 2 | Selection of heat pump installations to strengthen Poland's energy system, | $X_2$ | Dichotomic |
| 3 | Selection of other RES installations (solar installations, small wind installations) to strengthen Poland's energy system, | $X_3$ | Dichotomic |
| 4 | Building area up to 150 $m^2$ determining the choice of RES solutions | $Y_1$ | Numerical (scale 0–1) |
| 5 | Building area over 150 $m^2$ determining the choice of RES solutions | $Y_2$ | Numerical (scale 0–1) |

The specification of the results of the descriptive statistics of the variables are presented in Table 2.

**Table 2.** Specification of descriptive statistics results for the variables adopted.

| | śr. | SE | SD | $SD^2$ | Min. | Max. |
|---|---|---|---|---|---|---|
| $Y_1$ | 0.8671 | 0.0284 | 0.3406 | 0.1160 | 0 | 1 |
| $Y_2$ | 0.1328 | 0.0284 | 0.3406 | 0.1160 | 0 | 1 |
| $X_1$ | 0.8671 | 0.0825 | 0.9875 | 0.9751 | 0 | 3 |
| $X_2$ | 1.0349 | 0.0758 | 0.9070 | 0.8226 | 0 | 3 |
| $X_3$ | 0.3426 | 0.0723 | 0.8648 | 0.7478 | 0 | 3 |

The influence of explanatory variables ($X_1$—contribution of photovoltaic installations to strengthening the energy system of Poland, $X_2$—contribution of heat pump installations to strengthening the energy system of Poland, $X_3$—contribution of RES installations (solar installations, small wind installations) to the strengthening of the Polish energy system) and the explanatory variable ($Y_1$—an area of the building up to 150 $m^2$, determining the choice of RES solutions, $Y_2$—an area of the building above 150 $m^2$, determining the choice of RES solutions) were explained based on the logit regression model, according to the notation [40]:

$$ln\frac{p_i}{1-p_i} = Z_i = x^J\beta = \beta_0 + \beta^1 + \beta^2 X^1 i + \beta^2 X^2{}_i + \ldots + \beta_k X_{ki}$$

assuming:

$$ln\frac{p_i}{1-p_i} = logit\ (p_i)$$

The estimated quantities in this concept include $\beta_0 \ldots \beta_k$, which model the vector $\beta$. The estimation findings were captured using the odds ratio (OR) to clarify the thread of

whether the odds ratio for the parameter (*X_mi*) increased per unit (one unit) and whether the odds ratio excluding such an increase will be equal [41]:

$$\exp(\beta_m) = \frac{\Omega(x_i{}^m, X_{mi} + 1)}{\Omega(x_i{}^m, X_{mi})}$$

with assumptions:
$x_i{}^m$—a vector of variable $x_i$ is a vector without variable $X_{mi}$,
opportunity: $ln\frac{p_i}{1-p_i} = \exp(x_i{}^J\beta) = \exp(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki}) = \Omega(x_i)$

According to the above assumptions, an increase in the value of the parameter *X_mi* (assuming no variation in the rest of the factors) induces a change in the odds ratio in terms of $exp(\beta_m)$—times. In this situation, if:
$exp(\beta_m) > 0$—the odds ratio increases,
$exp(\beta_m) < 0$—the odds ratio decreases.

In this situation, the binary variable $X_m$, $exp(\beta_m)$ indicates the multiplicity of OR changes in terms of "$Y_i = 1$" for category "1" and variable $x_m$, relative to the odds ratio for category "0" and variable $x_m$. The results of the odds ratio change scale $\exp(\hat{\beta}_j)$ of the logit model $\hat{\beta}_j$ determine the OR values, where the average change is created by a unit increase in the variable [41,42]. The practice of this approach to the study of qualitative dichotomous variables is evident in the literature [43,44].

According to the above-mentioned findings, the process of transformation of the Polish energy system with the participation of innovative RES solutions—according to the adopted variables, can be captured in the range <0.1>—which means that the probability with the result $\leq 0.5$ indicates the transformation of the Polish energy system with the participation of RES solutions as a process independent of practical choices, while the results with estimated parameters > 0.5 indicate such a dependence. Capturing the obtained indications in the range of odds ratio > 1, makes it possible to isolate random actions and provides the possibility to determine the planned values in relation to the assumptions of the adopted research model [45].

The results of the logit regression models were established using the statistical instrument PQstat version 1.8.4.164.

The parameter correlation matrix according to the adopted model is presented in Table 3.

**Table 3.** Correlation matrix of the variables.

| Variable | $Y_1$ | $Y_2$ | $X_1$ | $X_2$ | $X_3$ |
|---|---|---|---|---|---|
| $Y_1$ | 1 | | | | |
| $Y_2$ | −1 | 1 | | | |
| $X_1$ | −0.5134 | 0.5134 | 1 | | |
| $X_2$ | −0.3951 | 0.3951 | 0.5870 | 1 | |
| $X_3$ | −0.4659 | 0.4659 | 0.5319 | 0.5053 | 1 |

The interdependence of variables adopts differentiated results in terms of the strength I ker of the interaction. The maximum positive degree of interdependence reaches a mean level, most strongly for the relationship $X_1$:$X_2$ (0.5870) and in the case of inverse correlation for the parameters $Y_1$:$X_1$ (−0.5134). In terms of the correlation analysis of the explanatory and explanatory variables, the correlation results assume a maximum mean positive level of 0.5134 for $Y_2$:$X_1$ and the inverse correlation a maximum negative level of −0.5134 for $Y_1$:$X_1$. The above indicates a moderate level of relationship between the explanatory and predictor variables, both in a positive direction, where the choice of heat pump installation increases with building area (above 150 $m^2$), and in a negative direction, where the choice of heat pumps decreases with decreasing area (below 150 $m^2$).

The further part of the paper presents the results of logistic regression for the adopted categories $Y_1$—building area up to 150 $m^2$ determining the choice of RES solutions, $Y_2$—building area over 150 $m^2$ determining the choice of RES solutions. A specification of the results of the descriptive statistics in terms of the effect of the $Y_1$ parameter on the variables adopted (vector parameter β, error size—b, confidence intervals—CI, Wald findings, odds ratio results—OR) is presented in Table 4.

**Table 4.** Specification of descriptive statistics results for the adopted variables (impact of $Y_1$).

| | β | Error b | −95% CI | +95% CI | Wald Stat. | OR Odds Ratio |
|---|---|---|---|---|---|---|
| $Y_1$ | 4.0580 | 0.7815 | 2.5261 | 5.5899 | 26.9576 | 57.8634 |
| $X_1$ | −1.6992 | 0.6797 | −3.0316 | −0.3669 | 6.2485 | 0.1828 |
| $X_2$ | 0.2606 | 0.4546 | −0.6304 | 1.1518 | 0.3287 | 1.2978 |
| $X_3$ | −0.2383 | 0.3333 | −0.8916 | 0.4150 | 0.1510 | 0.7879 |
| Pseudo R2 | 0.3319 | | | | | |

A specification of the results of the descriptive statistics in terms of the effect of the $Y_2$ parameter on the variables adopted (vector parameter β, error size—b, confidence intervals—CI, Wald findings, odds ratio results—OR) is presented in Table 5.

**Table 5.** Specification of descriptive statistics results for the adopted variables (impact of $Y_2$).

| | β | Error b | −95% CI | +95% CI | Wald Stat. | OR Odds Ratio |
|---|---|---|---|---|---|---|
| $Y_2$ | −4.0580 | 0.7815 | −5.5899 | −2.5261 | 26.9576 | 0.0172 |
| $X_1$ | 1.6992 | 0.6797 | 0.3696 | 3.0316 | 6.2485 | 5.4698 |
| $X_2$ | −0.2606 | 0.4546 | −1.1518 | 0.96–4 | 0.3287 | 0.7705 |
| $X_3$ | 0.2383 | 0.3333 | −0.4150 | 0.8916 | 0.1510 | 1.2691 |
| Pseudo R2 | 0.3319 | | | | | |

Based on the results of the findings, the $Y_1$ variable (building area up to 150 $m^2$ determining the choice of RES solutions) was considered basic and was first subjected to statistical testing. In the next step, the $Y_2$ variable was tested (building area over 150 $m^2$ determining the choice of RES solutions). The results of the estimation confirm the scale of significance of the tested models, where the odds ratio, reinforced with the findings regarding the Pseudo R2 parameter, enables the assessment of the level of model fit and provides the basis for interpreting the results of the estimation process.

Studies indicate that the highest probability of occurrence refers to the variable $X_1$ (selection of photovoltaic installations, strengthening Poland's energy system) within category $Y_2$ (odds ratio: 5.4698), although the OR for $Y_1$ is extremely low.

In the area of category $Y_1$, the distribution of results for variables $X_1$ (selection of photovoltaic installations, strengthening Poland's energy system) and $X_1$ (selection of heat pump installations to strengthen Poland's energy system) assumes a similar low character, with the OR for $Y_1$ as high as 57.8634 (with a low error: 0.7815), which creates a significant potential for their occurrence. The visualisation of the distribution of variables within individual categories is presented in Figure 5.

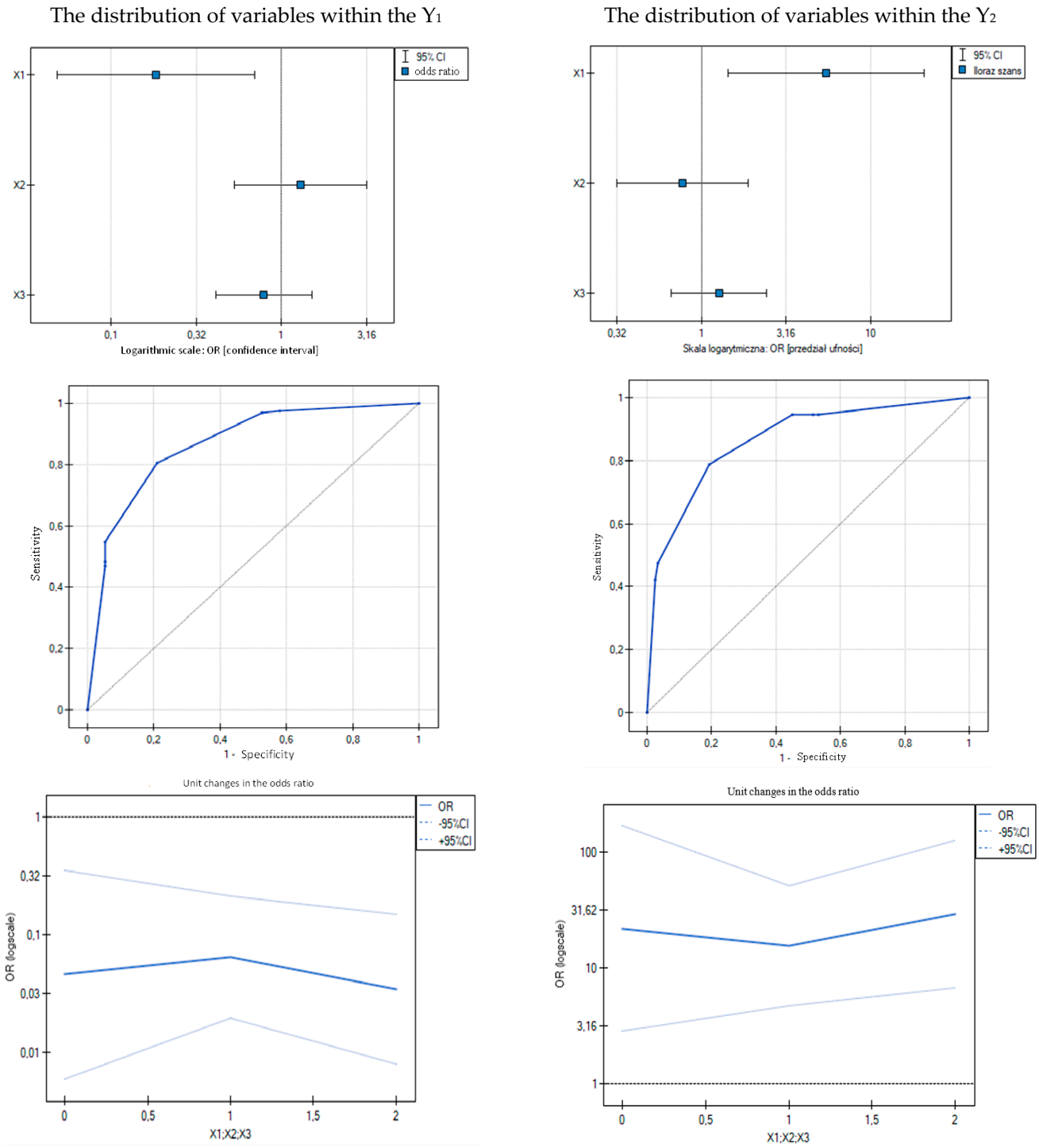


**Figure 5.** Visualisation of the distribution of variables within the $Y_1$ and $Y_2$ categories.

The research results indicate the relationship between solutions in the area of photovoltaics and heat pump installations. The relationship between these two dimensions is most strongly emphasised in the category of buildings over 150 $m^2$, where the odds ratio is relatively significant. In the case of buildings below 150 $m^2$, the relationship between these parameters is characterised by a weak relationship.

The results of the findings confirm the strong orientation of households towards RES solutions. The number of choices indicates a significant impact of RES solutions used in this dimension on the process of strengthening the Polish energy system. Importance in this respect should be attributed to photovoltaics, followed by heat pumps, as well as the

strengthening share of other solutions from the RES sphere (solar installations, small wind installations). The above gives grounds to positively verify the assumptions adopted in the study on the positive impact of the development of installations based on renewable energy sources at the household level on the process of transforming the energy system in Poland. In addition, confirmation of the significance of the impact of the factor related to the area of a building on the choice of RES solutions and their number in the analysed group of energy consumers confirms the motivation of choices related to the cost of maintenance of buildings, creating the need for investment challenges (buildings over 150 $m^2$). The above is a practical confirmation of the assumption that increasing the energy efficiency of buildings realistically creates a reduction in the cost of electricity consumption in connection with their operation. The growing demand for RES solutions dedicated to households contributes to stimulating the development of innovations and technologies in this field, which is deeply justified.

## 5. Discussion

The impact of RES solutions on development in both social and economic terms is widely analysed in the literature. I. Dincer pointed out a number of years ago that this dimension can positively influence a number of challenges of the contemporary world related to political-economic, as well as environmental or technical aspects [46]. The diverse directions of such an impact provide the basis for the development of innovation in this field, strongly demanded in the socio-economic dimension, driving its development. In this context, the promotion of this direction of change is strongly emphasised in the literature, where sustainable development is captured as a critical direction in the evolution of the world's economies, and the role of households in this process is widely explored and highlighted [47,48]. The positive impact of RES in this area is emphasised, among others, by A. Biernat-Jarka et al., who conducted a similar study on practical choices of RES solutions, drawing attention to their role in reducing the level of energy poverty, which in Poland affects as much as 9% of the community [49], as energy expenses constitute one of the main burdens on household budgets [50] E. J. Szymańska et al. in a similar strand of research point to similar choices in practical terms, articulating at the same time the barriers to the development of this dimension of household activity [44], which, as noted by D. Štreimikienė et al. are gradually being eliminated in the world [51]. M. Makešová et al., point to the impact of the RES dimension development on the process of strengthening economic well-being while emphasising the vital importance of this dimension in the process of energy systems transformation, giving grounds for locating it among the integral elements of this process [52]. In this respect, it is important to identify the determinants of RES development in the explored dimension, as emphasised by D. Kotsila et al. [53].

The positive impact of RES solutions on the process of strengthening the energy systems of world economies is obvious. The marked influence of small-scale energy consumers drawing on the RES dimension in Poland indicates an increase in the importance of this group of consumers in this country, which increases the degree of their real influence on the ongoing energy system transformation process. The interest in strengthening RES solutions in practical use at the household level provides a basis for predicting their importance in the further development of the RES dimension and its impact on the transformation process of the Polish energy system. Based on the results of the surveys constituting the input data for the analyses in this study, the authors found that 83% of the customers report full satisfaction with their choice of heating system type and 66% report interest in further development of their solutions, e.g.,—on an aggregate and multiple choice basis, towards energy banks (56%), solar installation (13%), wind installation components (18%), photovoltaic reinforcement (4%), heat recovery—recuperation (3%), or ecological fireplaces with higher energy efficiency (1%). This is a significant aspect of the changes taking place in this area, as small individual consumers are an ever-growing group of consumers who are increasingly influencing the modelling of the parameters of the transformation of the energy system in Poland.

Openness to innovation among the surveyed group of electricity consumers is not only innovation at the level of households and micro-enterprises, in connection with reaching for modern, ecological and energy-saving solutions. In addition to the solutions discussed in the sphere of energy supply in buildings, a very strongly observed dimension of innovation in this group of customers is the strongly developed management of energy consumption, using a range of instruments to support this activity. This confirms that the strong contemporary trend towards data acquisition and processing supported by new technologies [54,55] is also finding its way into the energy field. In this area, there are systems for programming temperature levels, air exchange volumes or, finally, tools for managing energy consumption at peak production times or times of attractive grid tariffs. Openness to these innovations is a strongly observed trend on modern farms. The number of control system solutions available is supplemented by applications enabling remote control and energy management. This reinforces consumer awareness, making it possible to manage energy consumption in a real way, strengthening energy efficiency. This shapes the price of electricity bills.

Greening and energy efficiency is an orientation towards devices powered by clean energy, which is evident in the charging stations planned for and installed, dedicated to, among other things, electric vehicles and other devices. Solar batteries as a source of for the farmyards of private properties is also an environmentally compatible, innovative, energy-saving trend.

Harnessing the potential of the sun, the energy of the earth or the wind is becoming increasingly popular and recognised. Ecological lifestyles are no longer a choice but a necessity, and designing solutions to reinforce eco-trends in energy consumption is the most appropriate direction for the energy market. Individual customers are open to innovation. The above is confirmed by the results of the survey, where the number of interests in RES solutions (the number of contracts executed by the surveyed company) increased by 8% year-on-year in 2021–2022, with a steady average growth of more than 8.5% between 2018 and 2022. The distribution of the growth trend is presented in Figure 6.

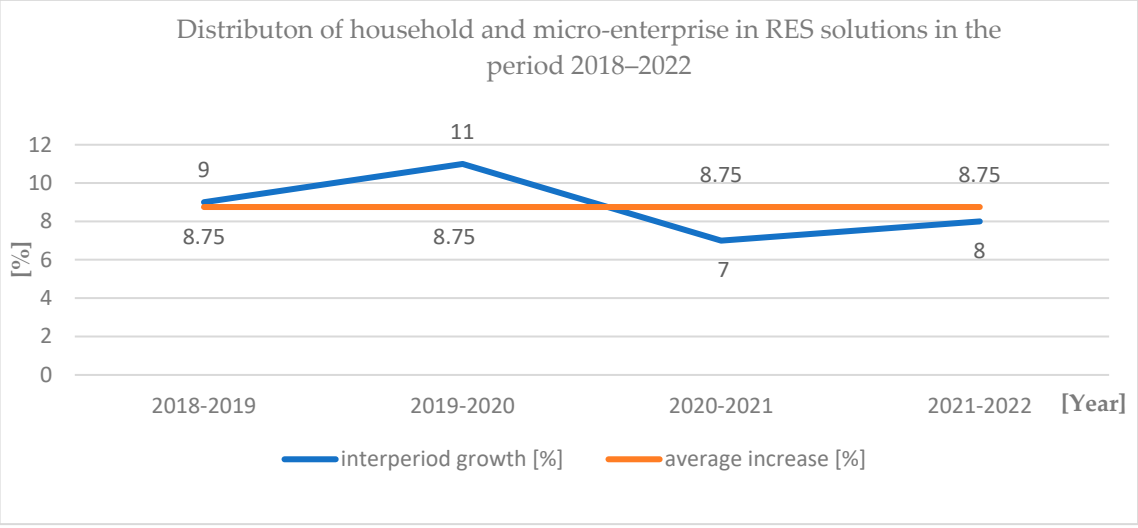


**Figure 6.** Distribution of household and micro-enterprise interest in RES solutions in the period 2019–2022.

The driving force for the design and implementation of environmentally friendly energy solutions is growing environmental awareness, which is strongly emphasised in the world literature [56,57]. Responsibility in this area is created by energy-saving-oriented behaviour, as well as an orientation towards obtaining energy for one's own needs (the energy balance aspect in energy awareness models of energy users). This idea guides the acceleration of design and construction processes for small-scale energy producers and

consumers (prosumers), who can actively participate in the production of energy for their own purposes and shape the level of energy use (energy management) and, as a result, take an active part in the transformation towards sustainable economies, as also signalled by M. Wijayaningtyas et al. [58]. This manifests itself in the trend of combining solutions in the design of new or the extension or modernisation of existing energy installations, which is a strong trend in Poland and worldwide towards the creation of pro-ecological solutions in the energy sector, also dedicated to small-scale energy consumers. When it comes to setting up or modernising installations for the benefit of individual small-scale investors, the focus is on increasing the individual security of energy consumers, as well as on providing opportunities for individual energy management to optimise the parameters of its acquisition and consumption. This contributes to a real reduction in electricity bills. The above indicates that the problems of social adaptation to progressive change, reported over the years by, among others, J. Meadowcroft, B. W. Terwel et al. or G. De Vries et al. [59–61], are losing some of their relevance, taking on a more limited scale. However, an important aspect of such development is also the long-standing theme of support for action by governmental bodies and institutions to overcome resistance or social constraints to innovation [14,62]. In this respect, friendly (pro-innovation) formal and legal regulations—with a particular focus on financial support instruments for RES initiatives—driving action to develop this dimension of investment are essential. This aspect should be regarded as a particularly important thread in the Polish economic reality that requires further improvement.

In addition to strengthening the awareness dimension in the sphere of environmentally and economically justified production of energy from RES sources based on new emission-free or low-emission solutions, an important dimension of the promotion of sustainable energy development in Poland is pointing to higher energy independence of consumers and comfort of use. The arrangement of individual needs and preferences regarding installations, as well as activities aimed at strengthening innovation in the broad sense of the term, determine its importance. This is because innovative solutions are in high demand, and their announcements motivate the search for paths to future openings for their application. Such examples include the announcements of ultrasonic heat pumps under construction in the world or wind solutions dedicated to small-scale users already being tested in Poland (Silesia Wind).

The system of needs and expectations regarding increasing the parameters of the energy generation and distribution process is linked to minimising the costs of acquiring electricity, combined with the comfort of use. In this respect, it is important to refine methods oriented towards energy efficiency, as well as more efficient ways of obtaining and managing energy consumption, as also highlighted by J. Arias-Gaviria et al. or C. S. Meena et al. [31,63]. A special role in this sphere can be played by new technologies in the sphere of management support (system applications), taking into account the artificial intelligence factor, studied by Q. Wu, or D. Madathil et al. [64,65].

Innovation in the field of energy absolutely contributes to improving the operational security of economies and significantly improves the parameters of the impact of human activity on the environment. This is realised by reducing the consumption of natural resources in favour of drawing from renewable sources, as well as reducing emissions and discharges of harmful substances into the environment. In addition to improving the safety of the use of new lines of energy based on RES, innovative efforts are oriented towards optimising the life cycle of electricity solutions to improve the parameters of the energy generation and distribution processes. Important aspects here are the management of plant components (capital intensity and life cycle of solutions) and energy itself (energy efficiency of energy generation and use of energy resources).

Poland is keeping pace with global trends in RES-oriented energy development. In addition to the world's most popular directions of obtaining energy from renewable sources (photovoltaics, wind energy or earth energy), which have been developed for years, there is improvement and practical use of solar installations which, by using energy derived from

the sun to heat water, can significantly contribute to reducing the negative impact on the environment, due to the reduction of the classical source of energy used for this purpose. The importance of the above in the field of energy is emphasised by Meena et al. [66], and the interest of investors in investing capital in this type of solution in Poland was confirmed by the results of the research discussed in this article.

## 6. Conclusions

The results of the presented research indicate that there is significant interest in RES solutions among individual energy consumers in Poland. This upward trend stems from a steadily increasing public awareness of the available sources of energy supply, as well as economic motivation, due to the numerous increases in rates for the purchase of 1 KW of energy on the free market. This upward trend may be further strengthened by state policy, oriented towards eliminating barriers and offering (financial) support by counteracting energy poverty, as well as realising the assumptions of modelling the energy mix in the Polish energy system towards sustainability. This is because new, innovative solutions create a significant financial challenge for private investors and, in a number of cases, are beyond the reach of small energy consumers.

The research conducted shows that the primary motivator for the move towards green energy is the aspect of high costs of property maintenance due to electricity charges, and the aim of reaching for investments in renewable energy is to reduce energy bills. In this regard, practical choices in the RES sphere are determined by the size of the building, where the size of the building determines the type and number of solutions. Photovoltaics is the leading choice, followed by heat pumps and then other solutions (solar installations, small wind installations). It should be emphasised that the findings refer to energy consumers who decide to invest in RES, including those who are interested in further developing their RES solutions. This dimension of small consumers investing in RES should be strengthened by developing support formulas for RES investments. This requires strong promotion of this course of action and higher availability of financial support from the state, which is the main conclusion of this research. The above findings can help decision-makers in designing a strategy for the development of the green energy market in Poland, with a particular focus on individual consumers.

The strong trend towards the development of the RES market at the level of small-scale energy consumers in Poland gives grounds for inferring a relatively high level of public awareness of the need for transformations in the country's energy system. Increased energy security, as a result of (at least partial) independence from energy suppliers, as well as savings from the mode of obtaining electricity for consumption purposes, are strong motivations for these actions. In addition, the energy efficiency of buildings is increasingly determining the purchasing decisions of Polish consumers in the real estate market. This aspect motivates investment in RES solutions as a kind of investment in a product that is in line with current trends and sellable now and in the future. The type and scope of innovative solutions applied create the market value of the property, which is also important for individual energy consumers investing in RES. (The value considered through this prism is particularly strongly reinforced in the group of buildings over 150 $m^2$, which, as the research shows, are equipped with numerous solutions from the RES sphere) The above indicates a significant and growing demand for RES solutions dedicated to this group of users. We are talking about solutions in the area of installation formulas (new solutions, effective integration of available solutions), as well as solutions in the area of support for energy production and use management, making buildings and premises intelligent in this area.

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