energies

Article

Analysis and Evaluation of the Possibility of Electricity Production from Small Photovoltaic Installations in Poland

Waldemar Izdebski [1] and Katarzyna Kosiorek [2,*]

[1] Faculty of Production Management, Warsaw University of Technology, Narbutta N. 85, 02-524 Warsaw, Poland
[2] Laboratory of Applied Microbiology, Institute of Biochemistry and Biophysics, Polish Academy of Sciences, Pawinskiego 5a, 02-106 Warsaw, Poland
* Correspondence: k.izdebska@ibb.waw.pl

Abstract: The production of electricity from photovoltaic (PV) systems is one of the significant opportunities for novel renewable energy sources. The PV systems can provide energy with minimum environmental harm; however, the usage of this energy source becomes strongly dependent on a wide range of social, economic, and technical factors. Based on the growing demand for renewable energy sources, the aim of the work focuses on the socio-economic analysis of possibilities of producing electricity from photovoltaic installations up to 10 kW in Poland. Based on expert research, the factors influencing energy production from PV systems were assessed based on factor three analysis (level II with 5 factors, level III with 15 factors). Using the expert-mathematical method, a hierarchy of economic, technical, and social factors of PV-based energy production was evaluated. The analysis of socio-economic factors indicated that the greatest impact on the PV systems development in Poland depends on energy purchasing costs and EU law regulations on renewable energy sources (RESs). The most influential factors were then used to forecast the possible cost-effectiveness of renewable energy production of home energy production. The study demonstrates the importance of renewable energy sources utilization and the cost-effectiveness of solar energy production in small PV systems in Poland.

Keywords: photovoltaic installations; production model; production costs; electricity

Citation: Izdebski, W.; Kosiorek, K. Analysis and Evaluation of the Possibility of Electricity Production from Small Photovoltaic Installations in Poland. *Energies* **2023**, *16*, 944. https://doi.org/10.3390/en16020944

Academic Editors: Massimo Dentice D'Accadia and Carlo Renno

Received: 7 November 2022
Revised: 12 December 2022
Accepted: 11 January 2023
Published: 14 January 2023

1. Introduction

The demographic, social, and economic evolution of human society has all depended on energy [1–3]. The European Union (EU) has consistently exceeded energy and climate goals, aiming to grow its contribution to renewable energy by at least 32% up to 2030 and to enhance its energy efficiency by 32.5% [4]. Because there is tremendous potential for energy consumption reduction and climate mitigation in European households, improving the energy performance of small home PV systems has been identified as one of the major aspects of achieving green energy targets [2]. One of the most urgent environmental concerns facing the globe now is climate change [5–7], thus installation of PV systems on the households' rooftops can provide a mitigation strategy for the increasing demand in future energy consumption and may play a crucial role in the development of clean and sustainable energy sources [8]. Therefore, the construction of innovative global energy production systems aimed at environmental sustainability must also take into account the energy produced by small PV systems [9,10].

In 2020, 27% of households were characterized as final energy consumers in the EU. In EU households, the most frequently used energy sources meeting final energy consumptions were natural gas (31.7%) and electricity (24.8%). The renewable energy sources used accounted for 20.3%, whereas the other energy sources were oil and petroleum products (12.3%) as well as derived heat (8.2%) [11]. The visible growth of renewable sources in the EU energy production mix is achieved thanks to significant investments in the area of the photovoltaics segment and energy obtained from wind farms [12]. The development of the photovoltaic market in the EU-28 countries is very dynamic. The installed capacity in photovoltaics increases every year and it is at a high level. In 2020, the installed capacity in the European Union in photovoltaics amounted to approximately 153 GW, this increase compared with 2019 reached the value of 18.8 GW. According to IRENA data, EU countries achieved a 14% increase in total installed PV capacity compared with 2019 [13].

In 2021 Poland was recognized as having the highest electricity production volume in history with 179.4 TWh produced [14]. The electricity demand reached a record of 180.3 TWh with the lowest value in the last five years in terms of net power imports. Currently, Polish domestic energy generation fulfills almost 99.5% of the electrical demand. In 2021, coal was the most used energy source and generated more than 72% of the nation's electricity. Despite estimates of the Polish population declining from 37.9 (in 2020) to 35.28 million (in 2040) [15], by 2040 there will be a significant rise in energy demand for the Polish household sector [14]. By assigning peak power related to winter and summer, the peak capacity demand for energy in Poland is estimated to grow by 1.9 GW and 1.5 GW, respectively, translating to 1.2% and 1.1%, respectively, of the annual growth rate between 2020 and 2040 [16].

According to the Institute of Renewable Energy, the full statistics of installed capacity in photovoltaic sources in Poland include:

- Small installations: installations with a total installed capacity not exceeding 50 kW, their total capacity amounted to 3022 MW at the end of 2020, and as of Q1 2021 it was 3500 MW;
- Installations with a capacity of 50 kW—500 kW, at the end of 2020 their installed capacity in Poland reached 65 MW, currently it exceeds 71 MW;
- Photovoltaic installations with a capacity of over 500 kW, their total installed capacity was estimated at 75 MW;
- Photovoltaic installations built as part of the RES auction: their installed capacity at the end of 2020 was 750 MW, and currently their capacity may be 820 MW, these are photovoltaic farms as well as solar power plants with a capacity of approx. 1 MW.

In Poland, the largest market share in green energy production is held by small photovoltaic installations. In 2021, their share accounted for 77% of the installed capacity in photovoltaics. In recent years, several important factors have resulted in a significant increase in interest in PV technology among households [17]. Among them, subsidies provided under Regional Operational Programs as well as the government co-financing program for photovoltaics, the "My Electricity" program, are recognized as the most important factors [18]. One of the possibilities for producing renewable energy in Poland is electricity from photovoltaic installations, both small installations usually placed on the roofs of residential houses or other buildings as well as the production of electricity from large photovoltaic installations so-called "photovoltaic farms".

Poland remains one of the leading EU laggards in the process of clean energy transition [13]. Poland produces 83% of its electricity from fossil fuels, which represents one of the highest rates throughout EU countries [14]. With only 17% of electricity based on renewable energy sources, Poland's green energy value is one of the lowest in the EU and countered only by much smaller CEE countries. Despite growing production volumes complemented by increasing total available production capacity, Poland's share of renewable energy sources dropped to ca. 17% (30 TWh) in 2021 [14]. From 2010, the capacity of conventional energy units has remained stable with 36 GW power capacity installed; however, since 2015 renewable energy sources (RESs) capacity has been visibly growing with compound annual growth at +4.4 GW/year, especially in the photovoltaics sector (+3.7 GW y/y). For this reason, the analysis of the solar energy production possibilities by households, especially in the context of their increased energy demand forecasts, is a significant aspect of the overall Polish energy system analyses in the upcoming years.

The presented paper attempts to assess the potential for electricity production from small domestic photovoltaic systems mostly installed on the roofs of single-family houses up to 10 kW in Poland. The phenomena of the growing possibilities of solar energy production in Poland represent the subject of many studies. The main areas of interest are photovoltaic installations' productivity [19], supporting infrastructure and energy storage [20,21], as well as the impact of photovoltaic panels on environmental sustainability [22]. The analysis of political, social, and economic factors influencing the growth of PV installations installed throughout the world has also been widely presented in the literature. Investments in photovoltaic installations are thought to be economically efficient in terms of photovoltaic power plants [23], energy storage [24], installations producing energy at the point of use (for personal use) in communal buildings [25], for public use [26], and industrial purposes [27]; however, there is a significant gap concerning the socio-economic analysis of the main important factors of production held by small PV systems in Poland. Therefore, the purpose of this study is to assess the potential for electricity production from small-scale photovoltaic installations, based on a prioritization analysis of the impact of social, economic, and technical factors on the development of this energy production in Poland.

According to the authors' best knowledge, issues that are related to the detailed analyses of various social and economic factors affecting the PV production effectiveness in Polish households have not been widely researched. Due to important economic and environmental challenges in the development of small PV systems, the primary objective of the presented study is to analyze and evaluate the optimum opportunities for the production of renewable solar energy in a changing economic and social environment in Poland. Auxiliary objectives of the presented article include:

1. Prioritizing factors influencing the costs effectiveness of small PV installations in Poland using the expert-mathematical method;
2. Determination of optimal strategy for solar energy production held by Polish households by analyzing the costs of electricity production from the levelized cost of electricity (LOCE) approach.

2. Methods

To evaluate the possibility of renewable electricity production from PV systems installations on single-family house rooftops in Poland, we distinguished the main research methods: (1) expert-mathematical method with statistical analysis prioritizing the most important socio-economical production factors; (2) and the levelized cost of electricity (LCOE) approach to evaluate the optimal cost-effective strategy for solar energy production held by Polish households.

2.1. Prioritization of Socio-Economic Factors of Small PV Installations System via the Expert-Mathematical Method

Analyzing the possibilities of production of PV-based energy from small installations in Poland, the importance of economic, social, and political factors were assessed through the use of the expert-mathematical method as presented previously [28,29]. A group of 91 experts was selected based on criteria discussed in detail in the literature [30]. A research questionnaire was developed containing 9 tables into which the experts entered ratings of the significance of a given factor in the assessed group and possible supplementary information on the given expertise. The first three tables contained information about the experts' employment and seniority in the field under study. The remaining six tables contained the factors at levels II and III of the event tree, in which experts entered the assessment expressing the magnitude of the impact of a given group and individual factors on the production of solar energy from slam PV systems in Poland. The factors listed in the tables were scored by the experts on a scale from 0 (irrelevant parameter) to 100 (maximum significance), with a total of 100 points (percentage) allocated to all analyzed parameters.

The minimum number of required experts was determined as presented before by Yevlanov et al. [31]:

$$N_E = \frac{f\beta(b-1)}{(\gamma+1)(b-1)\Theta_0} \tag{1}$$

where $f\beta\ (b-1)$ is the distribution quantile of χ^2 corresponding to the confidence level and number degrees of freedom $b-1$; γ is the assumed accuracy in assessing concordance; and Θ_0 is a critical value of the concordance coefficient.

The concordance factor was determined as presented:

$$\Theta = \frac{S}{\frac{1}{12}{N_E}^2(b^3-b) - N_E\sum_{i=1}^{N_E} T_i} \tag{2}$$

where p is the number of groups of identical series in the experts' assessment, and T_i is the number of repetitions of the same series in the analyzed group.

The number of repetitions T_i was evaluated as follows:

$$Ti = \frac{1}{12}\sum_{i=1}^{p}({t_i}^3 - t_i) \tag{3}$$

where t_i represents the index of similar series.

The concordance coefficient enables the quantitative assessment of experts' agreement and varies in the range of $0 \le \Theta \le 1$, where $\Theta = 0$ expresses a lack of experts' agreement, and $\Theta = 1$ means complete experts' agreement. In the situation of the critical value Θ close to or equal to 0, an increased number of experts must be taken into consideration.

The level of expert competencies was identified by the so-called competence coefficient, determined as presented before by Izdebski et al. [29]:

$$k = \frac{(k_i + k_A)}{2};\ 0 \ \le k \le 1 \tag{4}$$

where k_i is the informativeness factor addressing knowledge related to a given issue; and k_A is the argument factor.

The informativeness coefficient was established by the experts' self-evaluation of knowledge in a given issue (from 0 to 10 points) multiplied by 0.1. The argumentation factor was assigned by the discussion with an expert and assessing array values, as presented in Table 1. As presented previously by Yevlanov et al. [31], the value of k_A of 1.0 was considered as a high level of argument, the value between 0.8 and 1.0 as a medium, whereas 0.5 and below was assigned as a low argument level.

Table 1. Argument coefficient values used in the expert-mathematical method.

The Degree of Influence of the Source from the Experts' View	A High	B Medium	C Low
Theoretical knowledge in a given field	0.3	0.2	0.1
Work experience	0.5	0.4	0.2
Knowledge of domestic specialist literature	0.05	0.05	0.05
Knowledge of international professional literature	0.05	0.05	0.05
Intuition	0.1	0.1	0.1

2.2. Statistical Analysis

To assess the statistical significance of data gained from expert analysis, the analysis based on the χ-square criterion was used. A result was considered significant when the probability of a random difference was less than 0.001 ($p < 0.001$). The concordance of experts' research was checked through the coefficient of variance V_j as presented previously by Ayre et al. and Izdebski et al. [32,33]:

$$Vj = \frac{g_j}{\bar{m}_j} \tag{5}$$

where g_j is the mean square deviation of the important factor, and m_j corresponds to the local priority of the factor. As presented previously in the literature [33] the concordance of the experts' validity judgments was sufficient within the Vj parameter value below or equal to 0.25.

As a next step, the mean square deviation of the factor importance was determined as follows:

$$g_j = \sqrt{\frac{\sum_{i=1}^{N_E}(\bar{m}_j - m_{ij})^2}{N_E - 1}}, \text{ for } N_E \leq 30 \tag{6a}$$

$$g_j = \sqrt{\frac{\sum_{i=1}^{N_E}(\bar{m}_j - m_{ij})^2}{N_E}}, \text{ for } N_E > 30 \tag{6b}$$

The local priority m_j of the j_{th} factor was determined as follows:

$$m_j = \left(\sum_{i=1}^{N_E} m_{ij}\right)/N_E \tag{7}$$

2.3. ETA Analysis

The event tree evaluating the main factors affecting the energy production from PV systems in Poland was performed in order to provide simplification of the expert analysis output data as described previously [29].

2.4. The Levelized Cost of Electricity (LCOE)

To evaluate the net present value of a small PV system's total costs during the estimated operational period, the levelized cost of electricity (*LCOE*) index was applied. The levelized cost of energy (*LCOE*) in PLN/kWh was determined as follows:

$$LCOE = \frac{\sum_{t+1}^{n} \frac{I_t + O\&M_t + C_t}{(1+d)^t}}{\sum_{t=1}^{n} \frac{A_t}{(1+d)^t}} \tag{8}$$

where I_t is the total investment costs in the analyzed period in year t, $O\&M_t$ is the total annualized operation and maintenance systems costs in year t, C_t is the decommissioning cost of the plant in year t, A_t is the electricity generated in year t, d is the discount rate, and n is the estimated operational period (number of years).

Capital expenditure on the proposed model of on-grid small PV systems was collected from data from the Polish national subentry program "My electricity" to establish the cost necessary for domestic PV installations [34]. Data were additionally checked against IRENA data [35]. Maintenance and repair expenses of a PV small system at 101.9 PLN/kW/year for installation with a lifetime of 25 years were estimated. Photovoltaic decommissioning costs were assumed as presented in the Polish national subentry program "My electricity" to establish the cost necessary for domestic PV installations [34]. Power utilization rate and discount rate were assigned as presented previously in the literature [36,37].

In order to provide the forecasts of possible electricity changes in Poland, the inflation rate from 2010 to 2021 was used as the basis for the annual calculations as described previously [38,39]. Three possible scenarios of price changes were established. In the pessimistic scenario, the double value of average 2010–2022 inflation ratio was applied in annual calculations; the value of average 2010–2022 inflation ratio was applied in annual calculations; in an optimistic scenario value of average 2010–2022 inflation, the ratio was decreased twice and applied in annual calculations.

3. Results and Discussion

3.1. Economic and Social Aspects of Solar Energy Production in Small PV Installations in Poland

The progressive increase in prices for electricity in Poland forces small consumers, such as households, to look for opportunities of reducing the cost of electricity used. Moreover, increasing environmental protection requirements in Poland and the EU forces all energy consumers to look for new possibilities for renewable energy sources utilization. In Poland since 2020, the trend of installing an increased number of alternative heat sources has been observed [14]. Residents of single-family homes choose air-source heat pumps as an alternative heat solution instead of gas heating. However, heat pumps have a high demand for electricity both for heat extraction and for reheating buildings during periods of high-temperature drops. Thus, one way to reduce electricity costs while meeting environmental protection requirements is to install photovoltaic systems on residential rooftops, especially in single-family homes.

To evaluate the most important factors that can affect the possibilities of PV-based solar energy production by households in Poland, the expert elicitation approach was performed. A group of 91 experts was selected based on criteria discussed in detail in the literature [33]. A research questionnaire was developed containing 9 tables into which the expert entered ratings of the significance of a given factor in the assessed group and possible supplementary information on the given expertise. The first three tables contained information about the experts' employment and seniority in the field under study. The remaining six tables contained the factors at levels II and III of the event tree, in which experts entered the assessment expressing the magnitude of the impact of a given group and individual factors on the production of solar energy from slam PV systems in Poland. The factors listed in the tables were scored by the expert on a scale from 0 (irrelevant parameter) to 100 (maximum significance), with a total of 100 points (percentage) allocated to the individual parameters.

In the group of most important factors affecting the possibilities of energy production from small PV installations in Poland, experts distinguished well-known and structured factors, such as the costs of energy generation in photovoltaic installations, tax aspects of production, prices and availability of alternative energy resources, or the growing social awareness of the need to use renewable energy sources. However, in our research, we focused on the aspect of electricity prices in Poland, which have been changing significantly in recent years. We distinguished the growing pool of available grant funding from Polish and EU sources, which on the one hand can significantly improve the cost-effectiveness of energy production in PV systems, on the other can affect the increased interest in households in the installation of the PV systems.

As the most important factors determining the production of solar energy in small PV installations in Poland, we distinguished several economic aspects including prices and availability of conventional energy sources, PV energy generation costs, and grid electricity purchase costs. In the group of social factors also visibly affecting the number of undertaken PV installations in Poland we characterized: EU law regulations, environmental awareness regarding RES utilization, actions of conventional and renewable energy producers on the legislative processes of energy production in Poland, as well as technical possibilities of managing electricity produced from a photovoltaic installation (Figure 1).

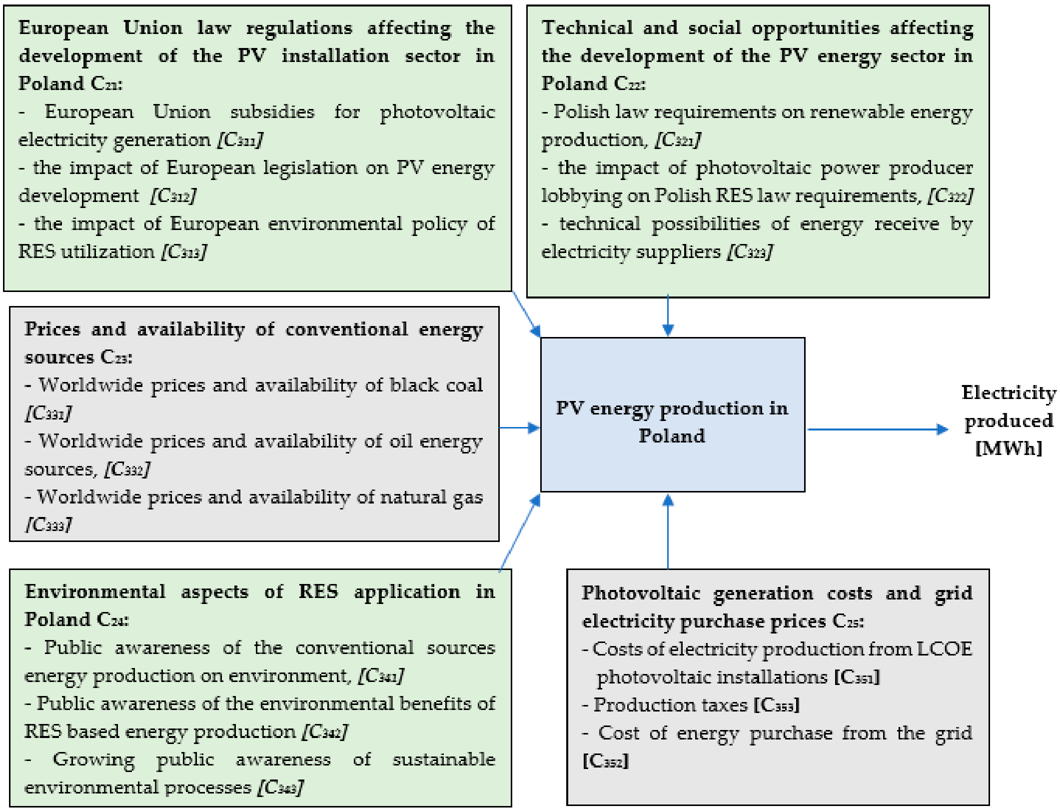

Figure 1. The set of economic and social factors influencing the selection of the most appropriate strategy for solar energy production in small PV systems in Poland. In the brackets, the levels of factors of importance used in the ETA tree are presented.

The economic factors with the greatest impact on the development of PV production efficacy in the small household system include the costs and availability of conventional energy sources (black coal, natural gas, or oils) as well as PV energy generation costs that should comply with PV energy taxes and costs of energy purchase from the grid. In the group of social factors, we distinguished legal and environmental factors. Legal factors include the possibility of obtaining subsidies from the European Union, and Polish funds as well as tax aspects of energy produced from PV systems. Environmental factors include the aspects of raw materials purchasing in a given region, the attitude of regional authorities and supervising offices, and the technical infrastructure availability which is crucial for the development of PV systems in households. The presented group of most important factors that can affect the energy production from PV small systems was in line with previous studies presented in the literature [9,40,41]. Based on a thorough analysis of the above factors, which can vary from extremely unfavorable to extremely favorable, the identification of the most important factors influencing the possibilities of solar production in small household systems becomes a particularly important aspect of RES sector development in Poland.

3.2. Prioritizing the Factors Influencing the Development of Small PV Systems in Poland

As presented in the literature [42–44], an ultimate indicator of a correctly adopted energy production strategy can be the minimum energy unit manufacturing cost, which requires the right balance of production factors in a changing economic and social environment. However, the mix of various economic, social, as well as political factors influencing the development of renewable energy production of PV systems in Poland represents a heterogenous group of elements that can significantly complicate the identification of minimum energy unit manufacturing cost. To provide a mathematical method enabling analysis of the identified incoherent group of factors, we applied the expert-mathematical method. The mentioned tool enables analyzing and evaluating diverse factors, and the results obtained by this method differ slightly from other methods in the range of 6–8% [28,29]. Hence this method can be applied for different economic purposes, including military, agricultural, or RES-based energy production [33]. Authorities' judgment in the expert-mathematical method is often based on the evaluation of various factors determining the problem, resulting in difficulty or inability to perform the analysis properly. To provide simplification to the expert survey analysis with more structured and reliable output data, the idea of the event tree analysis (ETA) was applied (Figure 2). The main objective (C1) and successive breaking down (decomposing) of this objective into increasingly subordinate objectives located at lower levels (2nd level: five factors labeled from C_{21} to C_{25} and fifteen 3rd level factors, labeled from C_{311} to C_{353}), resulted in a so-called "consequence tree" (Figure 2). The basic principle of building such a consequence tree is that each goal is related to only one overarching (more general) and many subordinate (more specific) goals.

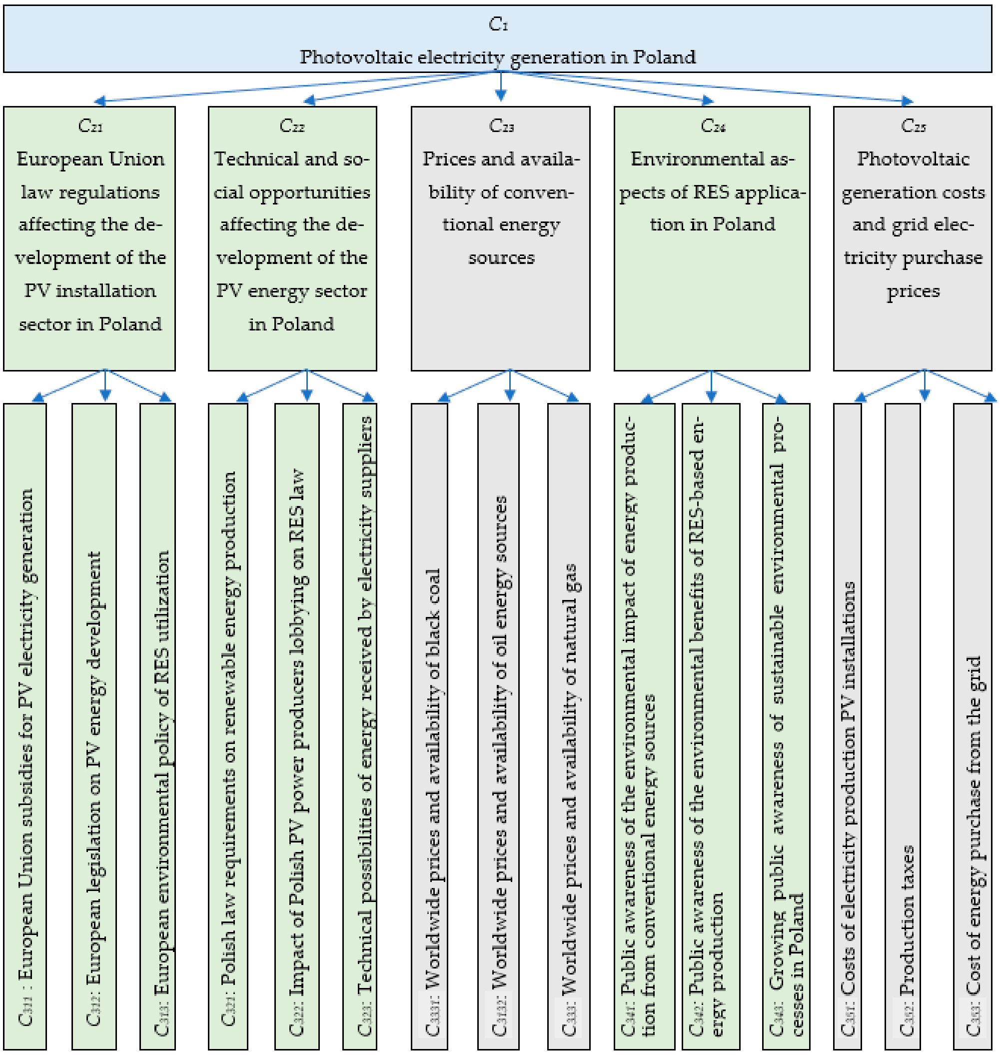

Figure 2. Input elements for the event tree analysis (ETA) assessing the main criteria (C) necessary for the cost-effectiveness of energy production in small PV systems in Poland. The presented tree shows a top-down, inductive procedure structuring the energy production possibilities in main

social or economic factors. C_1 is the initial event engaging energy production possibilities in small PV systems; C_{2X} is the level of factors assessing the various elements with potential economic and social influence on energy production from small PV systems; C_{3X} is the level of factors assessing the cost, technical, and environmental aspects of energy production from small PV systems.

In the ETA analysis (Figure 2), the importance of 5 level II factors (C_2) and 15 level III factors (C_3) determining the possibility of energy in small PV systems production in Poland (C_1) were estimated. The level II factors included various elements with potential economic and social influence on energy production from small PV systems (Figure 1, Table 2), whereas level III factors assessed the cost, technical, and environmental aspects of energy production from small PV systems in Poland. Data obtained from an expert survey were used to estimate so-called "local" and "system" priorities. Local priorities were obtained by the sum of points provided by experts and extrapolation to the value of 100. This approach enabled the identification of the share of each factor in the structure of the given group. Subsequently, the system priorities were calculated as a product of the local priorities from the lowest branch in the event tree (level III factors) to the level located at the top of the tree (level I), with the standardization condition based on the sum of system priorities at a given level (level II or level III) equal to 100. This approach enabled the identification of the "importance" of level II factors in all sets of elements rated by the experts by the value of local priority m_j (Table 2). The presented concordance coefficient at the value of 0.624 enabled the quantitative assessment of experts' agreement and met the applied compliance criterion in expert method analysis as presented previously in the literature [30] (Izdebski 2021).

Table 2. Assessment of the importance of level II factors conditioning the development of photovoltaic power generation in Poland in the expert-mathematical method. In the presented approach, 91 experts participated in the study of possibilities of small PV systems development in Poland assessment. A research questionnaire was developed containing 9 tables into which the expert entered information on knowledge in the related field of study, ratings of the significance of levels II and III factors in the assessed group, and possible supplementary information on the given expertise. Local priorities were obtained by the sum of points provided by experts and extrapolation to the value of 100. The system priorities were calculated as a product of the local priorities from the lowest branch in the event tree (level III factors) to the level located at the top of the tree (level I) (Figure 2), with the standardization condition based on the sum of system priorities at a given level (level II or level III) equal to 100. The approach enabled the identification of the "importance" of a given factor in all sets of elements rated by the experts by the value of local priority m_j (Table 2). The presented concordance coefficient at the value of 0.624 enabled the quantitative assessment of experts' agreement and met the applied compliance criterion in expert method analysis as presented previously in the literature.

Factor	Description	Value of Local Priority m_j	Coefficient of Variation V_j
C_{21}	European Union law regulations affecting the development of the PV installation sector in Poland	29	0.14
C_{22}	Technical and social opportunities affecting the development of the PV energy sector in Poland	16	0.11
C_{23}	Prices and availability of conventional energy sources	21	0.17
C_{24}	Environmental aspects of RES application in Poland	7	0.19
C_{25}	Photovoltaic generation costs and grid electricity purchase prices	27	0.14

Concordance ratio Θ_0	0.624
Criterion χ^2	29.79

As presented in Table 2, the most important level II factors (C_2) of energy production in small PV systems in Poland indicated by the expert method are European Union law regulations affecting the development of the PV installation sector in Poland (C_{21} factor) and PV energy generation costs with grid electricity purchase prices (C_{25} factor). Their cumulative share in the significance hierarchy in the evaluation of energy produced in small PV systems represented the value of 56 (56%). According to the experts' assay, the least important factors affecting the potential efficiency of energy production in small PV installations are environmental aspects of renewable energy sources (RESs) application, which account for only 7 points (7%) in the presented ranking.

To identify more detailed elements that can affect the level II (C_2) factors which consequently may also have an indirect impact on energy production in small PV systems in Poland, the systemic priorities values of level III factors (C_3) were also determined (Figure 3). For that purpose, in each distinguished II level (C_2) factor, four III (C_3) level factors were distinguished (Figure 1), expressing the potential role of the II level (C_2) group and indirectly the opportunities for the energy production process. The system priority value was calculated by multiplying the value of the local priority at a given level of the factor by the value of the local priority of the higher-level factor located in the given branch of the event tree.

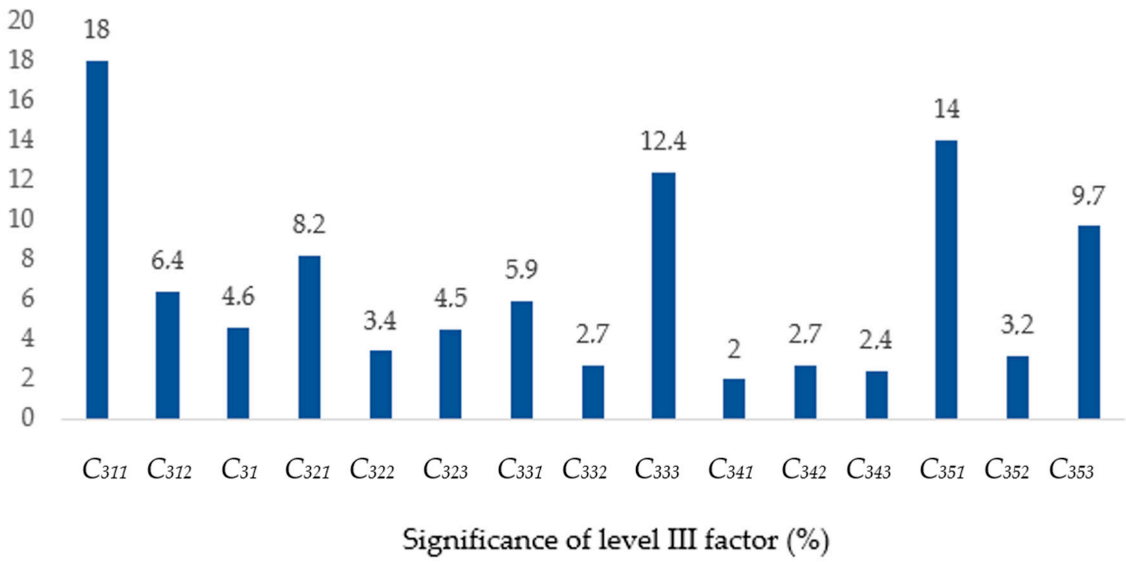

Figure 3. Assessment of the significance of level III factors (C_3) affecting the production of solar energy in small PV systems in Poland. Data on the diagram are presented ij percentage values. For each factor, system priority values were determined, which denoted their share in the hierarchy of significance of the main objective (C_1).

As presented in Figure 3, the magnitude of system priorities of the factors analyzed ranges from 2.0 to 18.0%, and the average value of one factor is equal to 5.0%. The largest share in the whole group on analyzed level III factors can be assigned to four elements: C_{311}, European Union subsidies for photovoltaic electricity generation (18.0%); C_{351}, costs of electricity production from LCOE photovoltaic installations (14.0%); C_{333}, worldwide prices and availability of natural gas (12.4%); and C_{321}, Polish law requirements on renewable energy production (8.2%). Contrary to expert opinion, public awareness of the conventional sources of energy production on the environment Poland presents the factor with the least impact on the development of solar energy production from small PV systems in Poland (2.0%).

The system priorities of level III factors were further divided into four ranges of significance ("weights"), that is: high, higher than average, average, and lower than average (Figure 4). Distinguishing of mentioned groups was based on the total range of system priorities with their average value of 5.0%. This approach led to the identification of the following ranges of importance: high (13.7–15.2%), higher than average (9.2–13.7%), average (4.6–9.1%), and lower than average (0.9–4.5%).

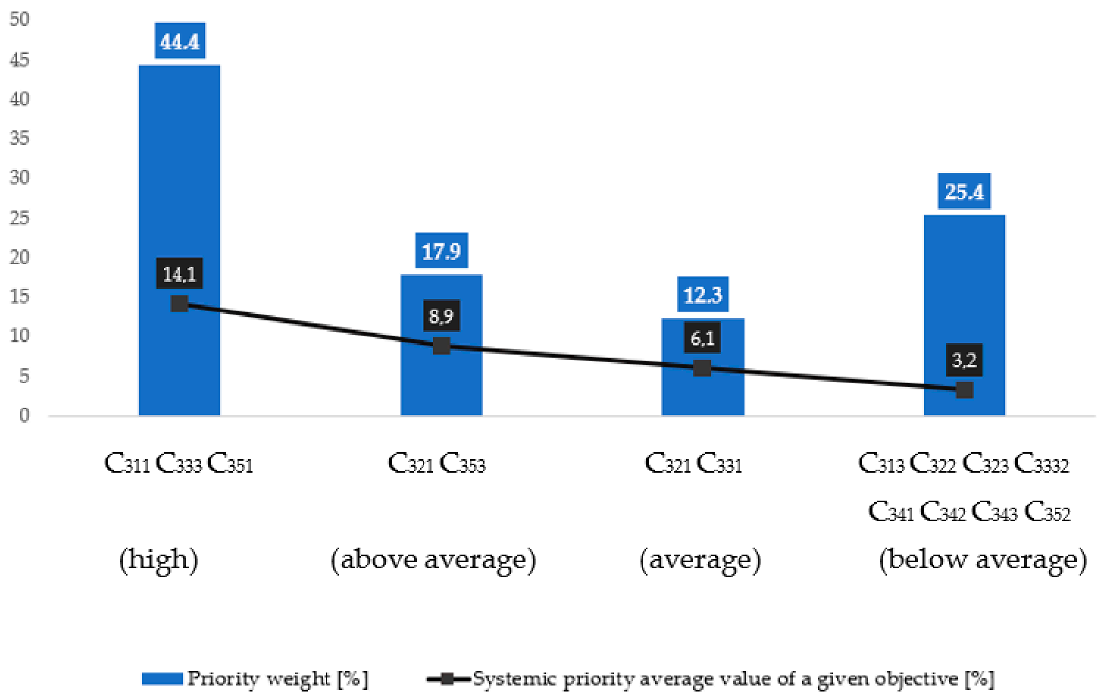

Figure 4. Hierarchy of importance of level III factors affecting the production of solar energy in small PV installations in Poland. The system priorities of level III factors were further divided into four ranges of significance ("weights"), that is: high, higher than average, average, and lower than average. Distinguishing of mentioned groups was based on the total range of system priorities with their average value of 5.0%. This approach led to the identification of the following ranges of importance: high (13.7–15.2%), higher than average (9.2–13.7%), average (4.6–9.1%), and lower than average (0.9–4.5%).

As a result of the expert-mathematical method (Figure 4), the factors regarding European Union subsidies for photovoltaic electricity generation (C_{311}), costs of electricity production from PV installations (C_{351}), and worldwide prices and availability of natural gas (C_{333}) were found in the range of highest significance (Figure 4). Therefore, those elements represent the most important factors affecting the possibilities of small PV systems sector in Poland. The presented results were in line with previously reported data indicating that EU subventions and general costs of PV systems installations represent the most important factor affecting RES energy sources used in general [9,41,45].

In Poland, EU subsidies for energy production from RES sources are operational regional programs managed by individual voivodeships. At the same time, the most popular option supported in operational regional programs is prosumer photovoltaic installations [18], with the application for funding prosumers to meet the many criteria evaluated as the readiness to implement the project. This includes the preparation of technical or environmental documentation with confirmation of supporting investment sources for PV installation [34]. The maximum share of the subsidy in the eligible expenditure for a given project is determined following the rules of public sources and it may not exceed the maximum 85 % of all installation costs. This funding can be provided in a non-refundable (grant) or refundable (loan with the possibility of partial cancellation) form. Based on data presented in the Production of Electric Energy in Poland, 2022 report [14] It is also possible for small producers of electricity from PV systems to use a tax deduction by investment costs for PV systems. This form of subsidy for photovoltaic installation in 2022 is proposed for public and single-family buildings used for residential purposes. In 2021 and until April 2022, there was a one-time subsidy of PLN 3,000 for newly built photovoltaic installations the National Environmental Protection Fund after meeting the requirements under the Regulation of the Minister of Environmental Protection [34].

The second distinguished group included two factors (C_{321} and C_{353}) Polish law requirements on renewable energy production and the cost of energy purchase from the grid, which may also be regarded as a relatively significant factor affecting the production process in Poland. In 2021, the Polish government decided to increase the share of renewable energy in total final consumption by 21–23% in its integrated National Energy and Climate Plan. To achieve these goals, the Polish government decided to provide more support to the renewable energy sector. In addition, support schemes for renewable energy (such as onshore wind farms and photovoltaic systems) were strengthened in 2021. This means that it cannot be funded beyond 31 December 2035 for up to 15 years, even though this period was extended to 30 June 2047 after the Renewable Energy Act was revised. It should also be noted that the solar power sector is generally the most dynamic and fastest-growing sector in Poland. Installed PV capacity at the end of 2020 was 3935.74 MW, according to the Renewable Energy Institute, based on an assessment based on data from Polish transmission system operator Polskie Sieci Elektroenergetyczne SA [46]. According to a report from the International Energy Agency, PV capacity was about 7.7 GW by the end of 2022 [47]. It has also been shown that PV capacity can reach 18–20 GW by 2025 [14].

With recent Polish climate policy changes, the government's low requirements state in line with our assumptions of the high range of this policy in small PV systems development in Poland.

The second distinguishing factor of the cost of energy purchase from the grid represents one of the major factors affecting PV installations. In Europe, the surge in electricity market prices is largely due to the rise in natural gas prices, which have risen sharply since late 2021. This is largely due to the economic recovery after the COVID-19 crisis and, to a lesser extent, reduced gas supplies from Russia. Electricity prices in Poland are currently relatively low as thermal coal is the fuel that determines the price. The war in Ukraine has yet to have a direct impact on European power market prices; however, household consumers in Poland are therefore seeking carbon-free electricity supply at the risk of high electricity prices continuing to rise over the next decade, and this factor should have a positive impact on the interest in small PV installations [13].

In the group characterized with an average of significance two factors, C_{312} and C_{331}, were identified. This group characterizes EU law requirements on PV energy manufacturers as well as worldwide prices and availability of black coal. EU law requirements on PV energy development represent a factor of great importance in European renewable sources utilization policy. According to the EU's Renewable Energy Sources Act [4], Poland was to achieve a 15% RES share in final energy consumption by 2020 to adhere to the RES policy outlined in EU legislation. Unfortunately, Poland was not able to meet this goal. Since Poland committed itself in its integrated national energy and climate plan to contribute to this target by achieving a 21–23% share of renewable energy in the gross final consumption, it became necessary to provide certain measures to expand the RES market [16]. The RES directive set forth the next ambitious target, which is the share of energy from renewable sources in the EU's gross final consumption of energy in 2030 shall be at least 32%. To achieve this goal, the Polish government may decide to revitalize the RES market by strengthening the auction support system and this element may significantly affect the perspectives of the PV small installations sector in Poland in upcoming years. The use of coal in the energy mix of countries, especially

Poland, is also an important aspect of the development of energy produced from renewable sources. In 2020, black energy in Poland's energy mix should fall below 70%, and the downward trend in coal power should continue for both environmental and economic reasons [14]. As a result, the importance and share of clean energy sources in the country's total energy production are increasing. This is due to solar and wind turbines for prosumers. This factor may positively affect the development of small PV installations in Poland in the upcoming years.

Eight factors were included in the fourth group, whose "system priority weight" of the whole range is quite significant, but the range significance resulted solely from the large number of factors included in this range. This implies no major effect on the economic effects of the production of energy from small PV systems in Poland.

3.3. Analysis of Electricity Production Costs in Photovoltaic Installations Using the LCOE Method

To evaluate the possibility of renewable electricity production from PV systems installations on single-family house rooftops in Poland, we analyzed the changes in the electricity prices in Poland over the last few years as well as the main changes in EU policy regarding subsidies for PV energy production.

According to data from the Polish Power Grid [16], electricity production in April 2022 amounted to 14,739 GWh, increasing by 9.94% in comparison with April 2021. Domestic consumption was slightly higher than a year earlier (by 4.21%) and amounted to 14,360 GWh (Table 3).

Table 3. Electricity production in April 2021–2022.

Specification	2021 [GWh]	2022 [GWh]	Change [%]
Total production	13,407	14,739	9.94
Commercial power plants	11,710	12,125	3.54
-professional water	292	303	3.57
-professional heat	11,418	11,822	3.54
-on hard coal	6892	7357	6.74
-on lignite	3608	3726	3.28
-gas	918	739	−19.46
Other renewable sources	457	846	84.91
Wind farms	1240	1769	42.7
Foreign exchange balance	373	−379	-
National electricity consumption	13,780	14,360	4.21

In April 2022, Poland's electricity production was significantly higher than a year earlier. Renewable energy sources had the highest growth rate. Production declined at gas-fired power plants, where domestic consumption was lower than production. In Poland, the largest amount of electricity comes from coal and lignite power plants whose total production in April 2022 was 11,083 GWh The third force in energy production is wind power plants, their production in April 2022 was 846 GWh. Production of other renewable energy sources during the period amounted to 846 GWh.

The average price of electricity for a household customer shown in Figure 5 also takes into account the distribution service fee, which is determined based on prices from comprehensive contracts concluded in a given year. According to Figure 5, the average price of electricity for households in the period analyzed increased from PLN 0.36 in 2001 to PLN 0.77 in April 2022, this is an increase of 113.9% in the analyzed period.

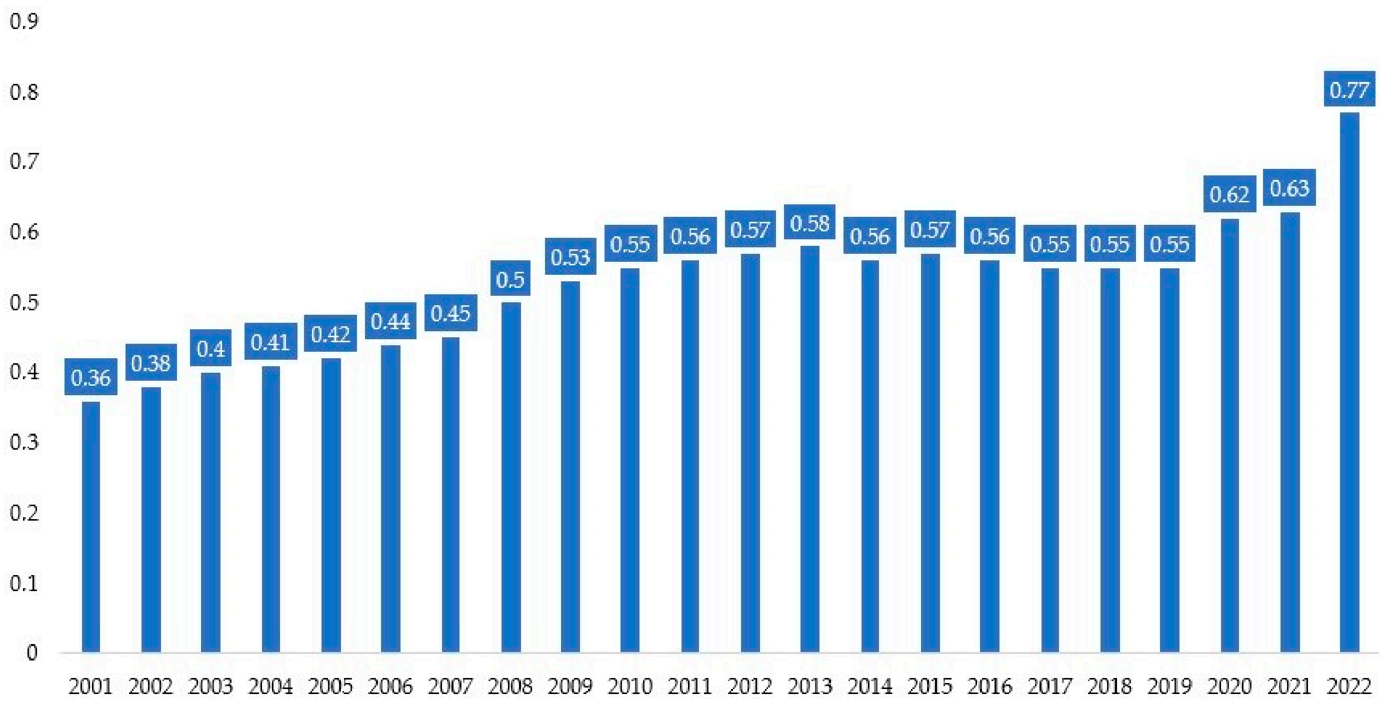

Figure 5. Average annual electricity prices in Poland from 2001 to 2022 [PLN/kWh] [16].

The expert-mathematical method presented in this study showed that the costs of electricity production from PV installations (C_{351}) may represent one of the most important features affecting the possibilities of solar energy production in small PV systems in Poland. Thus, in economic calculations focusing on estimating the potential cost of producing an electric unit in small PV installations, we focused on the aspect of potential changes in electricity prices in the adopted forecast period.

Analyzing the electricity prices changes in Poland in 2001–2022 as well as recent changes in the global inflation ratings [14,48], we prepared a forecast of electricity prices for 2023–2027 in an ex-post approach with three possible variants of the formation of possible future electricity prices, i.e., pessimistic, average, and optimistic variants (Figure 6).

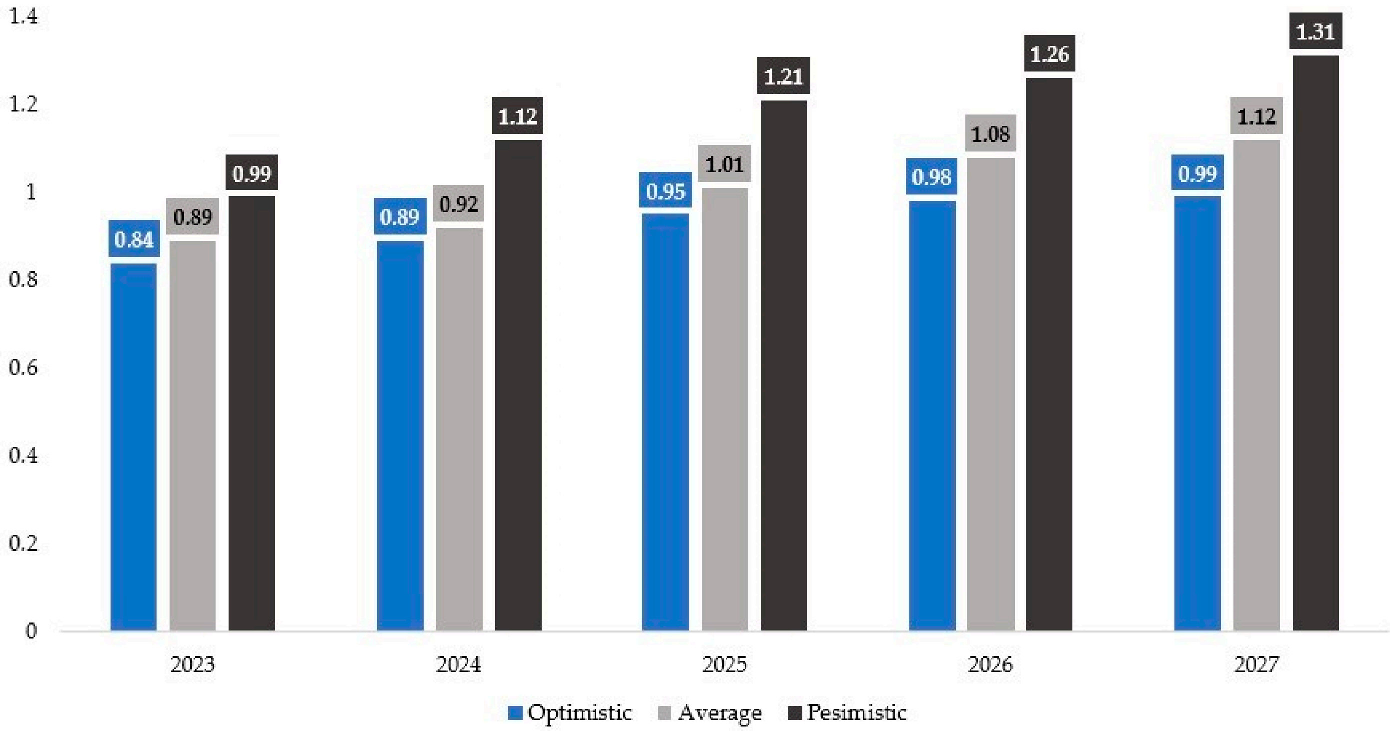

Figure 6. Electricity price forecast for households in 2023–2027 [PLN/kWh].

According to the optimistic variant, in the analyzed period we distinguished an increase in the price of 1 kWh of electricity from 0.84 in 2023 to 0.99 PLN/kWh in 2027 (change of +17.9%). In the medium variant, we assumed an increase in the price of 1 kWh from PLN 0.89 to PLN 1.12/kWh, (+25.8%). On the other hand, according to the pessimistic variant, in the analyzed period these prices will increase from PLN 0.99 to PLN 1.31/kWh, or by 32.3%.

To compare different renewable energy production technologies in terms of the economic efficiency of their production, we proposed the levelized cost of electricity (*LCOE*) index. In Table 4 all the necessary components of small domestic 10 kW photovoltaic installation costs were presented.

Table 4. *LCOE* costs for electricity production from a 10 kW photovoltaic installation in 2022 in Poland.

Data to Determine Production Costs	Unit	Components of Production Costs
Capital expenditures	PLN/kW	6337.10
Power utilization rate	%	13.00
O and M, maintenance, and repair expenses for a given year	PLN/kW	101.86
Service life	Years	25.00
Photovoltaic decommissioning costs	PLN/kWh	90.00
Discount rate	%	7.00
Unit production costs	PLN/kWh	0.49

As presented in Table 4, the largest value among presented components of the PV system is capital expenditures which amount to PLN 6337.10 per kWp, followed by maintenance and repair expenses and decommissioning costs of the PV system which amount to PLN 101.86 per kWh.

The unit production cost of the proposed 10 kW PV installation, a capacity utilization rate of 13%, 25 years of operation of this installation, a liquidation cost of PLN 90/kWh, and a discount rate of 7%, amounted to PLN 0.49 per kWh of electricity produced.

4. Conclusions

The progressive increase in prices for electricity in Poland forces small consumers, such as households, to look for opportunities of reducing the cost of electricity used. Moreover, increasing environmental protection requirements in Poland and the EU forces all energy consumers to look for new possibilities for renewable energy sources utilization. For that purpose, in the presented study an attempt was made to analyze a wide range of socio-economic factors that can affect the production of solar energy from small PV systems up to 10 kW in households in Poland. The PV systems can provide energy with minimum environmental harm; however, the usage of this energy source becomes strongly dependent on a wide range of social, economic, and technical factors.

To evaluate the most important factors, that can affect the possibilities of PV-based solar energy production by households in Poland, the expert elicitation approach was performed. In the group of most important factors affecting the possibilities of energy production from small PV installations in Poland, experts distinguished well-known and structured factors, such as the costs of energy generation in photovoltaic installations, tax aspects of production, prices, and availability of alternative energy resources or the growing social awareness of the need to use renewable energy sources. Based on expert research, the factors influencing energy production from PV systems were assessed based on event tree analysis (ETA) with five main factors of level II of hierarchy importance and 15 level III factors.

The most important level II factors (C_2) of energy production in small PV systems in Poland indicated by the expert method are European Union law regulations affecting the development of the PV installation sector in Poland (C_{21} factor) and PV energy generation costs with grid electricity purchase prices (C_{25} factor). Their cumulative share in the significance hierarchy in the evaluation of energy produced in small PV systems represented the value of 56 (56%). According to experts' assay, the least important factors affecting the potential efficiency of energy production in small PV installations are environmental aspects of renewable energy sources (RESs) application, which account for only 7 points (7%) in the presented ranking.

To identify more detailed elements that can affect the level II (C_2) factors, which as a consequence may also have an indirect impact on energy production in small PV systems in Poland, the systemic priorities values of level III factors (C_3) were also determined. The largest share in the whole group on analyzed level III factors can be assigned to four elements: C_{311}, European Union subsidies for photovoltaic electricity generation (18.0%); C_{351}, costs of electricity production from *LCOE* photovoltaic installations (14.0%); C_{333}, worldwide prices and availability of natural gas (12.4%); and C_{321}, Polish law requirements on renewable energy production (8.2%). Contrary to expert opinion, public awareness of the conventional sources of energy production on the environment Poland presents the factor with the least impact on the development of solar energy production from small PV systems in Poland (2.0%).

The expert-mathematical method presented in this study showed that the costs of electricity production from PV installations (C_{351}) may represent one of the most important features affecting the possibilities of solar energy production in small PV systems in Poland. To evaluate the possibility of renewable electricity production from PV systems installations on single-family house rooftops in Poland, the changes in the electricity prices in Poland in the last years as well as the main changes in EU policy regarding subsidies for PV energy production were analyzed. The average price of electricity for households in the period analyzed increased from PLN 0.36 in 2001 to PLN 0.77 in April 2022 (+113.9% year/year). This observation indicates that in the coming years, households in Poland will turn to alternative energy sources to compensate for the increasing prices of electricity from the grid. To compare different renewable energy production technologies in terms of the economic efficiency of their production, we proposed the levelized cost of electricity (*LCOE*) index. The largest value among the presented components of the PV system is capital expenditures which amount to PLN 6337.10 per kWp, followed by maintenance and repair expenses and decommissioning costs of the PV system which amount to PLN 101.86 per kWh. The unit production cost of the proposed 10 kW PV installation, a capacity utilization rate of 13%, 25 years of operation of this installation, a liquidation cost of PLN 90/kWh, and a discount rate of 7% amounted to PLN 0.49 per kWh of electricity produced. To identify mechanisms allowing the reduction in the unit cost of electricity generation, the factors of possible subsidies and tax reliefs available in Poland in 2021 and 2022 were analyzed. European Union subsidies for renewable energy in individual households also represents an interesting feature that can lead to a significant reduction in the investment costs of a small PV installation and, consequently, may reduce the value of the parameter of the minimum cost of electricity produced. In Poland, in 2021 and until April 2022, there was established a one-time subsidy of PLN 3,000 for newly built home photovoltaic installations up to 10 kW from the National Environmental Protection Fund. It is also possible for small producers of electricity from PV systems to use a tax deduction to reduce the income tax by the value of incurred investment costs for PV systems. As presented in the article, mentioned factors may have a significant impact on the development of the small PV installation sector in Poland in the coming years.

For all presented analyses, the following conclusions can be drawn:

1. Based on the expert research, 15 socio-economic factors affecting solar energy production in small PV systems in Poland were evaluated. The event tree analysis (ETA) provided simplification structurization of output research data. In the ETA methodology, five-level II factors and a total number of fifteen III-level factors in the hierarchy tree were identified;
2. Using the expert-mathematical method, a hierarchy of economic, technical, and social factors of PV-based energy production was evaluated. Analysis of socio-economic factors indicated that the greatest impact on the PV systems development in Poland depends on energy purchasing costs and EU law regulations on renewable energy sources (RESs);
3. In the Polish market, in 2021–2022 significant changes regarding electricity prices and available grants for small PV systems were observed. The average price of electricity for households in the period analyzed increased from PLN 0.36 in 2001 to PLN 0.77 in April 2022 (+113.9% year/year). There was established a one-time subsidy of PLN 3.000 for newly built home photovoltaic installations up to 10 kW from the National Environmental Protection Fund. It is also possible for small producers of electricity from PV systems to use a tax deduction to reduce the income tax by the value of incurred investment costs for PV systems. These factors may have a significant impact on the development of the small PV installation sector in Poland in the coming years;
4. To compare different renewable energy production technologies in terms of the economic efficiency of their production, we proposed the levelized cost of electricity (*LCOE*) index. The largest value among the presented components of the on-grid PV system is capital expenditures which amount to PLN 6337.10 per kWp, followed by maintenance and repair expenses and decommissioning costs of the PV system which amount to PLN 101.86 per kWh. The unit production cost of the proposed 10 kW PV installation, a capacity utilization rate of 13%, 25 years of operation of this installation, a liquidation cost of PLN 90/kWh, and a discount rate of 7%, amounted to PLN 0.49 per kWh of electricity produced. This value presented a much lower cost compared with the cost of buying electricity from the grid.

Production of electricity from small photovoltaic installations in Poland is one of the possibilities to improve the supply of clean renewable energy in Poland. The service life of this type of energy installation is over 20 years. Throughout the lifetime of these installations (20–25 years), the economic and social environment may change significantly, including: the price of electricity obtained from grid suppliers, the purchase price of electricity from photovoltaic installations delivered to the power grids, and law and tax requirements may also change. Therefore, in order to thoroughly analyze the economic efficiency of PV's installations, it is necessary to perform a detailed economic efficiency analysis throughout its operational period. For that purpose, future research directions can focus on the economic efficiency of electricity production from small photovoltaic installations in a turbulent economic and social environment throughout its operation.

Author Contributions: Conceptualization, W.I. and K.K.; methodology, W.I. and K.K; formal analysis, W.I.; investigation, W.I.; resources, W.I. and K.K.; data collection W.I.; writing—original draft preparation, W.I. and K.K.; writing—review and editing, K.K.; visualization, W.I. and K.K.; supervision, K.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

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

References

1. Ceran, B.; Jurasz, J.; Mielcarek, A.; Campana, P.E. PV systems integrated with commercial buildings for local and national peak load shaving in Poland. *J. Clean. Prod.* **2021**, *322*, 129076. https://doi.org/10.1016/j.jclepro.2021.129076.
2. Perea-Moreno, A.-J.; García-Cruz, A.; Novas, N.; Manzano-Agugliaro, F. Rooftop analysis for solar flat plate collector assessment to achieving sustainability energy. *J. Clean. Prod.* **2017**, *148*, 545–554. https://doi.org/10.1016/j.jclepro.2017.02.019.
3. Lukač; N.; Seme, S.; Dežan, K.; Žalik, B.; Štumberger, G. Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data. *Energy* **2016**, *107*, 854–865.
4. EU. *European Union Renewable Energy Directive 2018/2001/EU*; 2018. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG (accessed on 10 December 2022).
5. Bazazzadeh, H.; Nadolny, A.; Hashemi Safaei, S. Climate Change and Building Energy Consumption: A Review of the Impact of Weather Parameters Influenced by Climate Change on Household Heating and Cooling Demands of Buildings. *Eur. J. Sustain. Dev.* **2021**, *10*, 1. https://doi.org/10.14207/ejsd.2021.v10n2p1.
6. Clarke, L.; Eom, J.; Marten, E.H.; Horowitz, R.; Kyle, P.; Link, R.; Mignone, B.K.; Mundra, A.; Zhou, Y. Effects of long-term climate change on global building energy expenditures. *Energy Econ.* **2018**, *72*, 667–677. https://doi.org/10.1016/j.eneco.2018.01.003.
7. Guo, S.; Yan, D.; Hu, S.; An, J. Global comparison of building energy use data within the context of climate change. *Energy Build.* **2020**, *226*, 110362.
8. Victoria, M.; Haegel, N.; Peters, I.M.; Sinton, R.; Jäger-Waldau, A.; del Cañizo, C.; Breyer, C.; Stocks, M.; Blakers, A.; Kaizuka, I.; et al. Solar photovoltaics is ready to power a sustainable future. *Joule* **2021**, *5*, 1041–1056. https://doi.org/10.1016/j.joule.2021.03.005.
9. Akella, A.K.; Saini, R.P.; Sharma, M.P. Social, economical and environmental impacts of renewable energy systems. *Renew. Energy* **2009**, *34*, 390–396. https://doi.org/10.1016/j.renene.2008.05.002.
10. Chwieduk, B.; Chwieduk, D. Analysis of operation and energy performance of a heat pump driven by a PV system for space heating of a single family house in polish conditions. *Renew. Energy* **2021**, *165*, 117–126. https://doi.org/10.1016/j.renene.2020.11.026.
11. EuroSTAT Energy Consumption in Households. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households (accessed on 9 December 2022).
12. Tutak, M.; Brodny, J. Renewable energy consumption in economic sectors in the EU-27. The impact on economics, environment and conventional energy sources. A 20-year perspective. *J. Clean. Prod.* **2022**, *345*, 131076. https://doi.org/10.1016/j.jclepro.2022.131076.
13. EU Renewable Energy Targets. Available online: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en (accessed on 9 December 2022)
14. Polish International Trade Administration Poland Energy Sector. Available online: https://www.trade.gov/country-commercial-guides/poland-energy-sector (accessed on 8 December 2022)
15. STATISTA Population forecast for Poland from 2030 to 2100. Available online: https://www.statista.com/statistics/957308/poland-population-forecast/ (accessed on 11 December 2022).

16. Energetyczne, Polish Power System. *Development Plan for Meeting the Current and Future Electricity Demand for 2021–2030;* Energetyczne, Polish Power System: Konstancin Jeziorna, Poland, 2021.
17. Gawlik, L.; Szurlej, A.; Wyrwa, A. The impact of the long-term EU target for renewables on the structure of electricity production in Poland. *Energy* **2015**, *92*, 172–178. https://doi.org/10.1016/j.energy.2015.05.066.
18. Kulpa, J.; Olczak, P.; Surma, T.; Matuszewska, D. Comparison of Support Programs for the Development of Photovoltaics in Poland: My Electricity Program and the RES Auction System. *Energies* **2022**, *15*, 121. https://doi.org/10.3390/en15010121.
19. Zdyb, A.; Gulkowski, S. Performance Assessment of Four Different Photovoltaic Technologies in Poland. *Energies* **2020**, *13*, 196. https://doi.org/10.3390/en13010196.
20. Knutel, B.; Pierzyńska, A.; Dębowski, M.; Bukowski, P.; Dyjakon, A. Assessment of Energy Storage from Photovoltaic Installations in Poland Using Batteries or Hydrogen. *Energies* **2020**, *13*, 4023. https://doi.org/10.3390/en13154023.
21. Brodziński, Z.; Brodzińska, K.; Szadziun, M. Photovoltaic Farms—Economic Efficiency of Investments in North-East Poland. *Energies* **2021**, *14*, 2087. https://doi.org/10.3390/en14082087.
22. Hałacz, J.; Neugebauer, M.; Sołowiej, P.; Nalepa, K.; Wesołowski, M. Recycling Expired Photovoltaic Panels in Poland. In *Renewable Energy Sources: Engineering, Technology, Innovation*; Springer: Cham, Switzerland, 2019.
23. Dubey, S.; Jadhav, N.Y.; Zakirova, B. Socio-Economic and Environmental Impacts of Silicon Based Photovoltaic (PV) Technologies. *Energy Procedia* **2013**, *33*, 322–334. https://doi.org/10.1016/j.egypro.2013.05.073.
24. Salim, H.K.; Stewart, R.A.; Sahin, O.; Dudley, M. Drivers, barriers and enablers to end-of-life management of solar photovoltaic and battery energy storage systems: A systematic literature review. *J. Clean. Prod.* **2019**, *211*, 537–554. https://doi.org/10.1016/j.jclepro.2018.11.229.
25. Opiyo, N. Modelling Impacts of Socio-Economic Factors on Temporal Diffusion of PV-Based Communal Grids. *Smart Grid Renew. Energy* **2015**, *06*, 317–332. https://doi.org/10.4236/sgre.2015.612026.
26. Talavera, D.L.; Muñoz-Cerón, E.; de la Casa, J.; Ortega, M.J.; Almonacid, G. Energy and economic analysis for large-scale integration of small photovoltaic systems in buildings: The case of a public location in Southern Spain. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4310–4319. https://doi.org/10.1016/j.rser.2011.07.119.
27. Jousse, J.; Ginot, N.; Batard, C.; Lemaire, E. Power Line Communication Management of Battery Energy Storage in a Small-Scale Autonomous Photovoltaic System. *IEEE Trans. Smart Grid* **2017**, *8*, 2129–2137. https://doi.org/10.1109/TSG.2016.2517129.
28. Gordon, I.; Helman, O. *The RAND Corporation of Long Range Study*; RAND: Santa Monica, CA, USA, 1974.
29. Izdebski, W. *Strategia Wyposażania Gospodartsw w Kombajny Zbożowe*; SGGW: Warszawa, Poland, 2003.
30. Grzeszczyk, T.A.; Izdebski, W.; Izdebski, M.; Waściński, T. Socio-economic factors influencing the development of renewable energy production sector in Poland. *Econ. Manag.* **2021**, *24*, 38–54, https://doi.org/10.15240/tul/001/2021-1-003.
31. Yevlanov, L.G. Teoriya i praktika prinyatiya resheny. *Moscow Ekonomika* **1984**.
32. Ayre, C.; Scally, A.J. Critical Values for Lawshe's Content Validity Ratio: Revisiting the Original Methods of Calculation. *Meas. Eval. Couns. Dev.* **2014**, *47*, 79–86. https://doi.org/10.1177/0748175613513808.
33. Izdebski, W.; Skudlarski, J.; Zajac, S. Analysis of the significance of technological and organizational factors affecting the efficiency of agricultural tractors operation. *Teka Comm. Mot. Energy Agric.* **2012**, *12*, 323–329.
34. Polish Ministry of Climate and Environment My Electricity Subsidy Program. 2022. Available online: https://mojprad.gov.pl/ (accessed on 9 December 2022).
35. IRENA. *Renewable Energy Technologies: Cost Analysis Series Solar Photovoltaics*; 2021. Available online: https://www.irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis---Solar-Photovoltaics (accessed on 9 December 2022).
36. Akinyele, D.O.; Rayudu, R.K. Comprehensive techno-economic and environmental impact study of a localised photovoltaic power system (PPS) for off-grid communities. *Energy Convers. Manag.* **2016**, *124*, 266–279. https://doi.org/10.1016/j.enconman.2016.07.022.
37. Bhuiyan, M.M.H.; Asgar, M.A.; Mazumder, R.K.; Hussain, M. Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh. *Renew. Energy* **2000**, *21*, 403–410. https://doi.org/10.1016/S0960-1481(00)00041-0.
38. Zsiborács, H.; Hegedűsné Baranyai, N.; Csányi, S.; Vincze, A.; Pintér, G. Economic Analysis of Grid-Connected PV System Regulations: A Hungarian Case Study. *Electronics* **2019**, *8*, 149. https://doi.org/10.3390/electronics8020149.
39. Marcotrends Agency Inflation CPI in Poland 2010–2022. Available online: https://www.macrotrends.net/countries/POL/poland/inflation-rate-cpi (accessed on 11 December 2022).
40. Qiu, T.; Wang, L.; Lu, Y.; Zhang, M.; Qin, W.; Wang, S.; Wang, L. Potential assessment of photovoltaic power generation in China. *Renew. Sustain. Energy Rev.* **2022**, *154*, 111900. https://doi.org/10.1016/j.rser.2021.111900.
41. Peñaloza, D.; Mata, É.; Fransson, N.; Fridén, H.; Samperio, Á.; Quijano, A.; Cuneo, A. Social and market acceptance of photovoltaic panels and heat pumps in Europe: A literature review and survey. *Renew. Sustain. Energy Rev.* **2022**, *155*, 111867. https://doi.org/10.1016/j.rser.2021.111867.
42. Singh, G.K. Solar power generation by PV (photovoltaic) technology: A review. *Energy* **2013**, *53*, 1–13. https://doi.org/10.1016/j.energy.2013.02.057.
43. Wang, Y.; Das, R.; Putrus, G.; Kotter, R. Economic evaluation of photovoltaic and energy storage technologies for future domestic energy systems—A case study of the UK. *Energy* **2020**, *203*, 117826. https://doi.org/10.1016/j.energy.2020.117826.
44. Uzair, M.; ur Rehman, N.; Yousuf, M.U. Sensitivity analysis of capital and energy production cost for off-grid building integrated photovoltaic systems. *Renew. Energy* **2022**, *186*, 195–206. https://doi.org/10.1016/j.renene.2022.01.003.

45. Eftekhari Shahabad, M.; Mostafaeipour, A.; Hosseini Nasab, H.; Sadegheih, A.; Ao Xuan, H. A new model to investigate effects of subsidies for home solar power systems using system dynamics approach: A case study. *Sustain. Energy Technol. Assess.* **2022**, *49*, 101706. https://doi.org/10.1016/j.seta.2021.101706.
46. IEO Institute for Renewable Energy. *Photovoltaics in Poland 2020 Summary*; 2021. Available online: https://ieo.pl/en/86-en/news/1522-photovoltaics-in-poland-2020-summary-by-ieo (accessed on 11 December 2022).
47. IEA Poland 2022: Energy Policy Review. Available online: https://www.iea.org/events/poland-2022-energy-policy-review (accessed on 8 December 2022).
48. Chomać-Pierzecka, E.; Kokiel, A.; Rogozińska-Mitrut, J.; Sobczak, A.; Soboń, D.; Stasiak, J. Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States. *Energies* **2022**, *15*, 669. https://doi.org/10.3390/en15020669.