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Barriers and Prospects for the Development of Renewable Energy Sources in Poland during the Energy Crisis

Hubert Kryszk [1], Krystyna Kurowska [1,*], Renata Marks-Bielska [2], Stanisław Bielski [3] and Bartłomiej Eźlakowski [1]

1 Department of Land Management and Geographic Information Systems, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Prawocheńskiego 15, 10-695 Olsztyn, Poland
2 Faculty of Economic Sciences, University of Warmia and Mazury in Olsztyn, Oczapowskiego 4, 10-719 Olsztyn, Poland
3 Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, Oczapowskiego 8, 10-718 Olsztyn, Poland
* Correspondence: krystyna.kurowska@uwm.edu.pl; Tel.: +48-89-523-42-81

Abstract: Europe is currently facing the potentially biggest energy crisis in history. There are many reasons for this, and the current geopolitical situation makes it clear that we are being forced to take immediate action to ensure sufficient energy supplies to consumers. Until recently, the European Union was dependent on Russian energy resources (mainly oil and gas). For many years, the EU countries had been shutting down their own production and importing much cheaper raw material from Russia. The threat of a blackout is becoming increasingly possible. European governments are preparing businesses and households for the energy crisis in various ways, but there is also a great deal of mobilization to accelerate the development of renewable energy sources (RES). The aim of this study was to identify the barriers and prospects for RES development in Poland in the current geopolitical conditions. The reasons for insufficient grid HC were analyzed. Additionally, the article aimed to assess the prospects for solar energy development in Poland. Wind power was discussed only in general terms because the development of wind farms is inhibited by the regulatory framework. Particular attention was paid to hosting capacity (HC) and the condition of the power infrastructure as the main determinants of RES development in Poland. Numerous documents developed by power companies and government agencies responsible for implementing and managing energy in Poland were analyzed. Special attention was paid to legal regulations and the need for legislative changes. As a country, Poland has one of the highest growth rates in photovoltaic (PV) installations. The forecasts for increasing HC, as a prerequisite for RES development in Poland, are not promising.

Keywords: connection to the power grid; energy crisis; legal requirements; photovoltaic power stations; renewable energy sources

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1. Introduction

In recent months, energy security has emerged as the greatest concern in Europe. Energy security has numerous definitions, including the absence of a threat to continuous energy supply [1]. Energy security also denotes all means and processes that are deployed to guarantee the supply of power if an energy source is cut off, as well as energy resource deposits that are available in each country and constitute energy reserves if international agreements ended. Energy security is also defined as the lack of concern for an uninterrupted supply of electricity, the ability to supply energy independently, and stable energy and resource supplies that guarantee self-reliance [2,3]. Energy security is closely associated with economic security because the power industry is one of the pillars of every economy.

Polish law defines energy security as a state of the economy which guarantees that the demand for fuel and energy will be effectively met in a technically and economically justified manner without violating environmental protection requirements [4] (Article 3, point 16).

The first decade of the 21st century witnessed a rapid increase in energy prices and growing instability on the global energy market. These processes can be attributed to both the growing awareness that global energy resources are being depleted and the rising ambitions and significance of the world's leading suppliers of fossil fuels. The prices of energy resources influence economic development, and countries with the greatest abundance of fossil fuels realized that they could rely on their natural wealth to exert pressure on consumers. In addition to geopolitical factors, energy security is also affected by climate, social, and technical factors in countries that both mine and import fossil fuels [5].

Europe is currently facing what may be the greatest energy crisis in history, comparable to the 1973 oil crisis [6–8]. The oil crisis of 1973 forced nations to examine their energy use and efficiency [9]. Campaigns encouraging users to save energy were launched in Europe and the USA. Various strategies and methods were proposed to cut energy consumption; for example, lights in shop windows were turned off past 10 p.m., lighted Christmas decorations were not put up, and heating temperatures were reduced in public buildings. The British government appealed to its citizens to heat only one room in the household [7]. The 1973 oil crisis also changed attitudes towards energy security. Beginning in the 1970s, France launched 56 nuclear power plants over 15 years. Germany became the world's leading producer of renewable energy (mainly wind and solar energy).

There are numerous reasons for the present energy crisis, but there is no doubt that the reduced supply of Russian gas and the EU embargo on Russian gas, oil, and coal have markedly contributed to the present situation in Europe [10]. The current geopolitical situation leaves no doubt that urgent measures are needed to guarantee stable oil and gas supplies. European governments are implementing various measures to prepare private and industrial consumers for the energy crisis. Different scenarios are being proposed to minimize the risk of recession. The crisis has forced Europe and other continents to switch back to coal. Many EU countries are reactivating coal-fired power plants, including Germany, which operates the largest number of such plants in Europe. Energy saving measures are being implemented in Western Europe. Hanover has turned off heating in indoor and outdoor swimming pools. The Spanish government is encouraging consumers to monitor power consumption in households and turn off unnecessary lights. France has laid out temperature guidelines for heating and air-conditioning in buildings. Energy security has resurfaced as a major problem in the 21st century, and Europeans could be forced to restrict their energy use. There is a real risk of a blackout unless European countries accumulate sufficient gas reserves before winter and introduce energy conservation measures.

A blackout is defined as a sudden drop in voltage in power transmission lines covering vast parts of a country. There are many different types of interactions that can cause failures to spread during the course of a blackout [11]. In most cases, blackouts are caused by a combination of random events, such as the grid failure and emergency shutdown of a large power plant that occurs when the main operating parameters exceed critical values in the power supply system. As a result, successive power plants can be automatically cut off from the grid, leading to cascading failure in the entire affected area. Such events can occur under various operating conditions, including in systems with sufficient energy reserves to cover current demand, regardless of the season. Failures caused by extreme weather events can also lead to local power outages [12,13]. Dobson et al. [14] analyzed power outages in a number of countries and concluded that the power law is responsible for the frequency with which large blackouts occur. Power supply systems are highly complex networks which are designed to ensure that power supply to critical loads is not interrupted. The power law suggests that serious blackouts have consequential effects and that cascading failure can be expected when the total load on a system exceeds its operating limits [11,15–17]. Fotis et al. [18] identified other risks, including RES output volatility, problems with matching electricity supply with energy demand, cyberattacks, and unpredictable events in the power grid. According to the cited authors, these factors make the risk of a blackout more probable than in the previous years.

Recent years have also brought a radical change in attitudes towards energy security, marked by a shift from expensive fossil fuels to renewable energy sources (RES). The transition to renewable energy is inevitable and irreversible. The reinstatement of coal-fired plants is disappointing and, hopefully, only a temporary setback, but the future belongs to RES. The reduced supply of energy from Russia is likely to accelerate the transition to RES. Photovoltaic (PV) systems are the most popular RES in Poland. The forecasts for increasing the hosting capacity (HC) of Polish power plants, as a prerequisite for RES development, are also promising.

Hosting capacity denotes the maximum amount of distributed energy generation that can be safely and reliably integrated into the power grid without triggering changes in voltage quality or requiring changes in the power distribution system [19]. Zain ul Abideen et al. [20] define HC as the maximum amount of distributed energy resources (DERs) that can be accommodated by a distribution network without necessitating changes in the existing infrastructure. Distribution system operators (DSOs), regulatory authorities, and researchers use HC as both a term and a methodology. Hosting capacity has been calculated in many research studies, especially in power distribution networks and new energy sources [21]. In order to accommodate renewable energy generation in their grids, large DSOs analyze HC as part of their strategic operations [19,22].

Our previous study [23] demonstrated that PV development in Poland is thwarted mainly by insufficient HC of the power grid. Numerous factors impede the development of solar projects in Poland, including local factors such as terrain, sun exposure, shape of the land plot for PV plant construction, as well as the low availability of medium-voltage lines. The absence of a main transformer station in the area of the planned solar farm poses the greatest obstacle to PV development in Poland.

Fatima et al. [24] have proposed several definitions of HC: as the ratio of customers that are part of a Distributed Generation (DG) program; as the proportion of rated power from PV in the entire connected load; as transformer rating; or as the present peak demand of the feeder.

Hosting capacity is the prime factor in integrating large amounts of RES, especially PVs, into distribution networks, which contributes to a reduction in the carbon footprint. Hosting capacity values can differ considerably, depending on whether HC is defined as the peak load, transformer rating, or the number of customers with PV permits. Power networks that are excessively burdened with distributed generation (DG) systems can experience numerous problems, including overvoltage and undervoltage, loss of entire power lines, transformer and feeder overloading, failure of protective systems, and significant variations in high harmonics that violate international standards. These problems are observed when a power system exceeds its HC limit [25].

In the literature, the HC of low-voltage distribution grids for connecting solar PV installations has been calculated with the use of various methods. Different approaches to quantifying the HC of low-voltage distribution systems for connecting residential PV installations have been compared by Koirala et al. [26]. According to Zain ul Abideen et al. [20], data availability and the type of research performed determine the selection of tools and methods for quantifying a grid's HC. Various approaches to calculating the amount of solar power that can be safely accommodated by a power grid have been reviewed by Mulenga et al. [27]. Torquato et al. [28] relied on the Monte Carlo method to analyze HC and overvoltage. Schäler et al. [29] created a digital twin of a low-voltage grid to detect grid bottlenecks based on the true status of a physical grid and to match grid investments to actual needs in the distribution grid. This novel approach can be used to rationally plan HC. A valid concern has been expressed by Manowska and Nawrot [30], who observed that RES may not be sufficient to power the grid and resolve the current energy crisis in Europe. In 2016, a team of Polish researchers (Igliński et al.) [31] published a study on the prospects for the development of windfarms in Poland. They observed that wind energy has considerable growth potential in Poland. The researchers concluded that the draft act on wind energy projects poses the greatest threat to the development of windfarms in Poland. Unfortunately, the act was adopted on 1 January 2016, and it effectively blocked the development of this RES in Poland. According to Muszyński and Kocur-Bera [32], the development of the wind power sector is also impeded by other factors, including a very long and complicated investment process, complex formal and legal procedures, spatial and environmental restrictions, and low public awareness about the benefits of RES. However, Li et al. [33] observed that RES significantly contributes to energy security, environmental protection, and employment.

Novel technologies implemented during the stages where new RES installations are designed or existing power grids are expanded and upgraded will also play a key role in RES development in the future. Innovative and intelligent grids have attracted considerable interest in recent years, and there have been many recent publications using artificial intelligence and machine learning [34,35]. According to Borunda et al. [36], machine learning can be used to predict PV power output on a regional scale. Fotis et al. [37] presented the FLEXITRANSTORE project, which integrates hardware and software solutions in all areas of the transmission system and the wholesale energy market, harnesses the potential of power generation systems, and promotes the penetration of RES on the European market.

The aim of this study was to identify the barriers and prospects for RES development in Poland in the current geopolitical situation. The reasons for insufficient grid HC were analyzed. The additional aim of the article was to assess the prospects for solar energy development in Poland. The study focuses on solar power, and wind power was discussed only in general terms because the development of wind farms is inhibited by the regulatory framework. Particular attention was paid to HC and the condition of the power infrastructure as the main determinants of RES development in Poland. This research was motivated by the volatile situation on the energy market and the steep increase in electricity prices in recent months. Poland's energy policy should focus mainly on expanding and upgrading the national power grid. The article has the following structure: Section 1 contains the introduction, which highlights the main problems related to energy security, the energy crisis, RES development in Poland, the legal framework, and contains a definition of HC. The research methodology is presented in Section 2. Section 3 describes the condition and the HC of the Polish power grid, presents forecasts for the coming years, and examines energy prices on the global market. The results are discussed in Section 4, and conclusions are formulated in Section 5.

2. Materials and Methods

The study focuses on solar power, and wind power was discussed only in general terms because the development of wind farms is inhibited by the regulatory framework. Particular attention was paid to hosting capacity (HC) and the condition of power infrastructure as the main determinants of RES development in Poland.

The following reports were used in the analysis: the Photovoltaic Market in Poland (2022) [38], the Supreme Audit Office Report (2021) [39], and annual reports developed by Poland's leading DSOs [40–44]. Business data from the RES market and the latest information about the energy crisis, current energy prices, and market prospects for the coming years were also important sources of information for the research. The study also relied on the reports and papers published by scientific centers, energy companies, and government institutions. Legal regulations applicable to the operation and development of the Polish RES sector were also analyzed. The analysis covers a period of rapid PV development in Poland, and it includes DSOs' forecasts concerning the connection of new renewable energy generation assets to the power grid by 2027. Data for the study were also obtained from energy industry websites. The condition of Polish power infrastructure was considered in the analysis.

The HC declared by Polish DSOs was analyzed [40–44]. Network operators identify groups of coherent generators for which maximum HC values are then defined. Groups of nodes that are mutually correlated in terms of sensitivity coefficients are identified in this approach. Based on a table of sensitivity coefficients, the correlations between the identified nodes were analyzed, and the impact of generators on line loading was determined. Groups of significantly correlated coherent generators were identified. In the next step, the maximum energy generation that can be reliably incorporated into the grid was determined for each group of the identified nodes. This goal was achieved by increasing generation in groups until overload (which does not take place without additional generation or without increasing the existing overloads).

The calculations relied on power grid models for the summer season. Changes in grid structure (new nodes and connections, changes in line load) resulting from new power infrastructure projects completed and planned by the Polish DSOs were taken into consideration. All power infrastructure projects planned in a given year, i.e., the energy contracted until 2027, were included in the models. The remaining determinants of RES development, mostly PV systems, were identified based on a review of the literature and industry websites dedicated to the solar energy market in Poland and other European countries.

The power grid models for the summer season were developed based on the following assumptions:

- energy consumption is higher in summer (cooling and air-conditioning equipment),
- energy generation efficiency is highest in summer.

The above factors pose a significant load on Poland's outdated grid.

3. Results

3.1. Hosting Capacity and Prospects for Development

In Poland, DSOs are legally required to draft development plans covering their respective regions of operation (to cater to present and future demand). These documents are the main sources of information about DSOs' investment strategies, including infrastructure development projects that are designed both to connect new users to the grid and to increase grid reliability and the quality of power transmission services.

In Polish regions, electricity is supplied by the following major distribution companies [23,45,46]:

- ENEA—voivodeships of West Pomerania (Szczecin), Lubusz (Gorzów Wielkopolski, Zielona Góra) Wielkopolska (Poznań), Kuyavia-Pomerania (Bydgoszcz);
- ENERGA—voivodeships of Pomerania (Gdańsk, Gdynia, Słupsk, Koszalin), Wielkopolska (Kalisz), Kuyavia-Pomerania (Toruń), Warmia and Mazury (Olsztyn, Elbląg);
- PGE—voivodeships of Podlasie (Białystok), Mazovia (excluding Warsaw), Łódź (Łódź), Świętokrzyskie (Kielce), Lublin (Lublin), Podkarpacie (Rzeszów);
- TAURON—voivodeships of Małopolska (Kraków), Silesia (Katowice), Opole (Opole), Lower Silesia (Wrocław);
- Stoen (controlled by E.ON)—the capital city of Warsaw.

Stoen is a local operator that supplies energy only in the Warsaw region; therefore, it was not included in the analysis. PKP Energetyka is another DOS that manages dispersed energy infrastructure for the Polish railways. Railway transport is a very important sector of the national economy, which is why green energy solutions should be implemented in this industry. Railway power lines have different supply voltage, but PKP Energetyka has a vast HC (Figure 1).

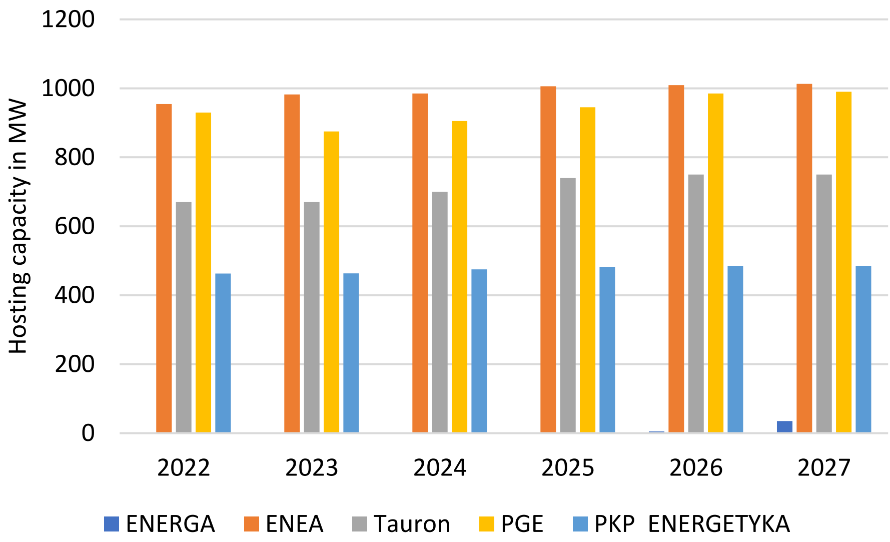

Figure 1. Hosting capacity of Polish distribution system operators (in MW) in 2022–2027 [40–44].

Enea and PGE, which supply power mainly in north-western Poland, have the largest HC. Tauron, which operates in south-western Poland, is also a major player on the domestic energy market. The market status of Polish DSOs is dictated largely by historical factors as well as the socioeconomic development of Polish regions. Eastern Poland is less developed and less industrialized (with a predominance of agriculture), and it is characterized by a lower number of energy consumers.

The options for connecting renewable generation assets to the power grid are determined by two key factors:

- the operating parameters of transmission and distribution networks (110 kV), including line overloads under normal and emergency (n − 1) conditions;
- a DSO's ability to balance the National Power Grid, i.e., balance the demand for and supply of electricity.

3.2. The Influence of Legal Regulations on the Installed Capacity of PV Systems

According to the 2010 National Renewable Energy Action Plan, the total installed capacity of PV systems in Poland would reach 1.8 GW in 2020 and 10 GW in 2030 (2 MW in the base scenario!). Meanwhile, installed solar capacity exceeded these projections more than two-fold already in mid-2020, and it reached 10 GW in the first half of 2022 (Figure 2). Poland's first solar farm in Wierzchosławice had an installed capacity of only 1 MWp when it was commissioned for use in 2011, which increased the load from grid-tied PV systems by more than 10% percent. At present, the corresponding load would be less than 0.1%.

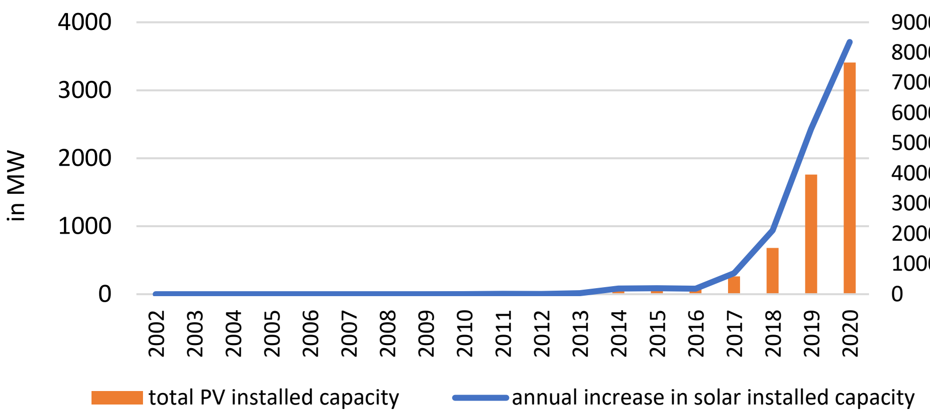

Figure 2. Total PV installed capacity and the annual increase in solar installed capacity in Poland [38].

It was only in 2019 that the installed capacity of PV systems in Poland exceeded 1 GWp. However, this parameter increased by another 1 GWp in less than 12 months. In 2021, PV installed capacity increased by 1 GWp within two months, and solar energy farms became the leading green technology with the largest installed capacity (7.7 GWp) in Poland.

Since 2010, numerous programs have been implemented to promote the development of the solar energy sector in Poland. The main initiatives were:

- 2010—National Renewable Energy Action Plan with a scenario for PV development until 2023;
- 2011—first PV farm (1 MWp) in Wierzchosławice;
- 2012—draft of the Renewable Energy Act with feed-in tariffs for electricity generated from PV systems;
- 2013—prosumers were released from the legal obligation to apply for grid connection conditions;
- 2014—"Prosument" program;
- 2015—implementation of the Renewable Energy Act with feed-in tariffs;
- 2016—net metering ("premiums"); first RES auctions;
- 2018—"My Electricity" program, tax relief for prosuments;
- 2021—amendments to the Renewable Energy Act in the part concerning solar energy tariffs.

The efforts aiming to promote RES development were thwarted after 2016 due to the political situation in Poland and the new government's reluctance to move away from coal. The Polish PV market witnessed radical changes in 2022. The amendments to the Energy Act [4], implemented on 1 April 2022, completely changed feed-in tariffs for PV prosumers (who applied for grid connection after 1 April 2022). The amended act introduced a net billing scheme, where prosumers are charged based on the actual consumption of electricity. The amount of consumed energy is balanced against the energy injected into the grid based on average monthly prices quoted on the energy market (as of 2024, energy prices will be calculated in the day-ahead market timeframe). The generated surplus will be virtually credited to the prosumer's account and can be used in the future to pay for the energy drawn from the grid based on current market prices. As in the discount scheme, the credits will be accumulated within a 12-month billing period. As a result, surplus energy generated in summer can be used to decrease electricity bills in winter. Prosumers who fail to inject the required amount of energy into the grid will have to pay for their energy consumption. Prosumers who generate surplus energy will be entitled to a refund, but not more than 20% of the energy that was injected into the grid in a given calendar month. The above rules do not apply to prosumers who signed a PV purchase or installation agreement with a local government or businesses implementing RES projects financed from a Regional Operational Program before 31 March 2022 or to prosumers who apply for a grid connection before 31 December 2023 [47].

As of 2022, large PV systems will be entitled to several benefits that had been introduced in 2021. Public support for leading renewable energy producers will be prolonged. At present, the following support options are available, depending on the type of producer:

- renewables auctions, where PV, wind, and hydraulic power plants sell energy at fixed prices over a period of 15 years after winning the auction;
- the seller is obliged to purchase renewable energy from RES systems with a capacity of 50–500 kW;
- a system of premiums.

In line with the amended act, RES auctions about which the EU is notified will be prolonged until 31 December 2027, and guaranteed feed-in tariffs (FiT) and feed-in premiums (FiP) will be prolonged until 30 June 2024.

Legal regulations pose the greatest obstacle to the development of onshore wind farms (the 10H rule introduced in 2016 banned the construction of wind farms within a distance of less than 10 times the height of wind turbines in residential and protected areas). Efforts have been made to change the regulatory framework, but to date, a satisfactory outcome has not been reached. Legislative problems have recently resurfaced in the face of the energy crisis in Poland and the world.

According to a recent study conducted by the Polish Academy of Sciences [48], the 10H rule prevents the construction of wind farms on 99% of Polish territory. Wind turbines cannot be installed at a distance of less than 2 m from residential and protected areas. Not a single wind farm permit has been issued since the 10H rule was introduced in 2016. Projects that are currently underway had been approved for construction before 2016. The Polish government is planning to introduce a price cap on solar-generated energy at 30% of the price quoted on the energy exchange. This move could lead to the collapse of the Polish RES sector. Poland has a favorable climate for RES development, but effective policies are needed to harness the potential of wind and solar power.

Considerable advancements in solar technology have been made in the past decade. Silicon PV cells evolved from the BSF (18% conversion efficiency in 2012) to the PERC technology (24% conversion efficiency in 2022), and TOPCon, HJT, and IBC solar cells with 25–26% conversion efficiency are currently mass produced. The conversion efficiency of PV panels has been increasing at an annual rate of 0.6% [38].

Poland met its 2020 target of a minimum of 15% renewable energy consumption in gross final energy consumption. This target was imposed by the Renewable Energy Directive I (2009) which was implemented to promote the green energy transformation. The share of renewables in Poland's gross final energy consumption reached 16.1%.

3.3. Condition of Power Infrastructure

In the Polish law, the safety of the power infrastructure is defined as the uninterrupted operation of the national power grid and compliance with power quality parameters and customer service standards, including acceptable outages under foreseeable operating conditions (Energy Law, Article 3, point 16b) [4]. This definition is largely influenced by the technical condition of Polish power infrastructure. A survey of Polish solar energy businesses [38] revealed that low HC and rejection of new connection applications due to grid aging and instability are perceived as the main barriers to the growth of the PV market. The age structure of Poland's power infrastructure is presented in Figure 3.

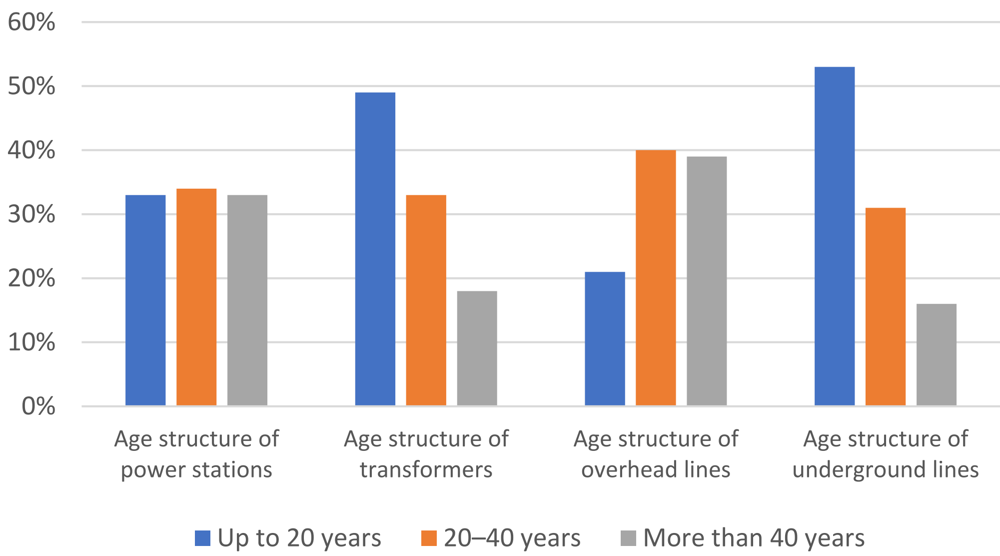

Figure 3. Age structure of Poland's power infrastructure [38].

Outdated overhead lines (39% of lines are more than 40 years old) and power stations (33% of stations are more than 40 years old) significantly limit the connection of new renewable power plants to the grid. Dilapidated power infrastructure is the main reason for the rejection of connection applications. Data for 2015–2021 are presented in Figure 4.

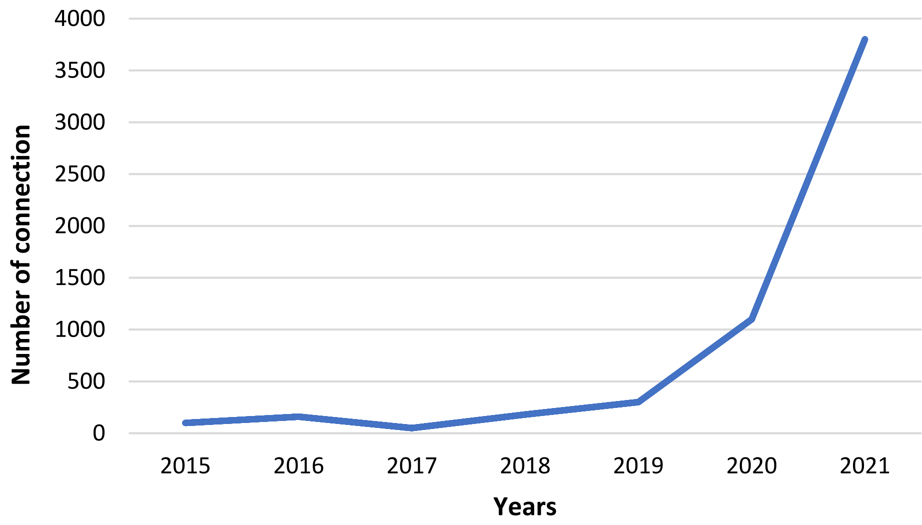

Figure 4. Number of rejected connection applications in 2015–2021.

More than 6000 grid connection applications were rejected between 2015 and 2012. According to the Energy Regulatory Office [45], around 30 GW of energy were rejected during that period, which accounts for roughly 50% of the total installed capacity in both conventional and renewable power plants in Poland (as of April 2022) (Figure 5). The largest number of applications were rejected in the last two years of the analyzed period.

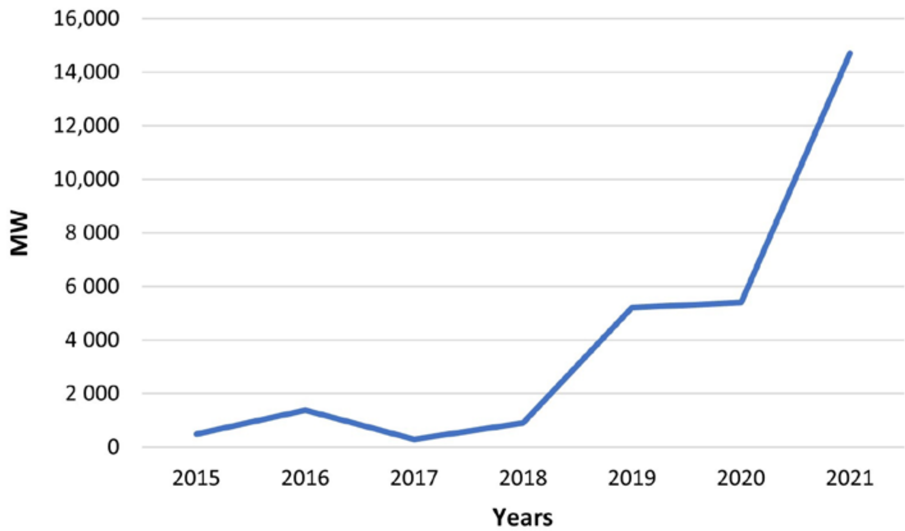

Figure 5. Installed capacity of rejected power plants (MW) in 2015–2021.

Investors often do not have access to valid information about the HC of the main transformer stations or the DSOs' plans to increase the HC of local power networks. A potential investor has to submit an application to a power distribution company to determine whether the planned PV system can be connected to the grid. The administrative procedure is long, and numerous documents have to be attached to the application. This explains the high rejection rate (both in terms of the number of projects and their installed capacity).

When issuing grid connection requirements, DSOs often indicate transformer stations that are located remotely from the planned power plant, which significantly increases investment costs.

The number of connection applications rejected by Polish DSOs between 2017 and 2021 is presented in Figure 6.

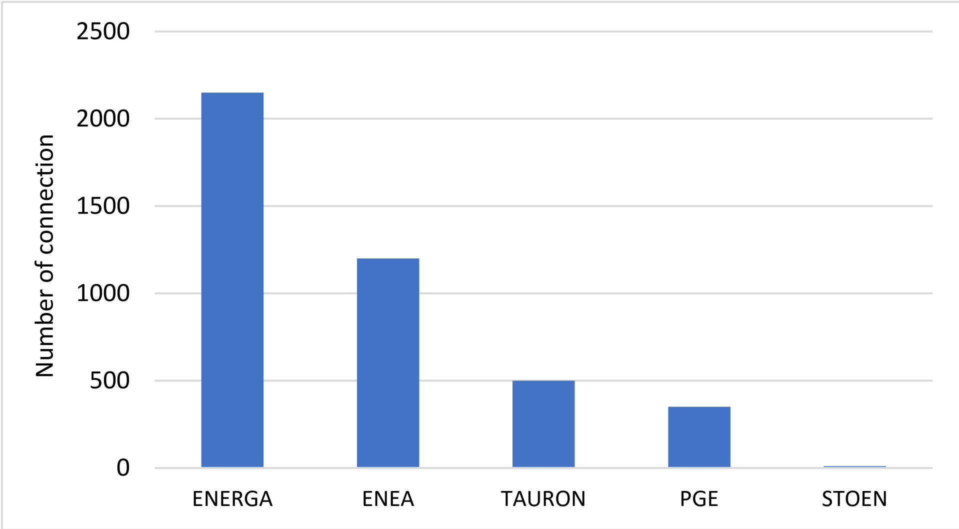

Figure 6. Number of connection applications rejected by Polish distribution system operators between 2017 and 2021.

Between 2017 and 2021, the largest number of connection applications were rejected by Energa, which operates mostly in northern Poland. The large number of rejections can be attributed mainly to Energa's low HC, but they also testify to the growing interest in renewable energy projects, including PV systems, throughout Poland.

3.4. The Impact of the Energy Crisis on Electricity Prices

The present crisis concerns not only crude oil but also gas and coal, which are heat carriers. For many years, Russia had been the main supplier of energy raw materials in Europe. Restricted supplies of coal, oil, and gas on the Polish market will drive up global prices. In Poland, electricity prices have increased dramatically since April 2022, particularly for businesses. The corresponding data are presented in Figure 7.

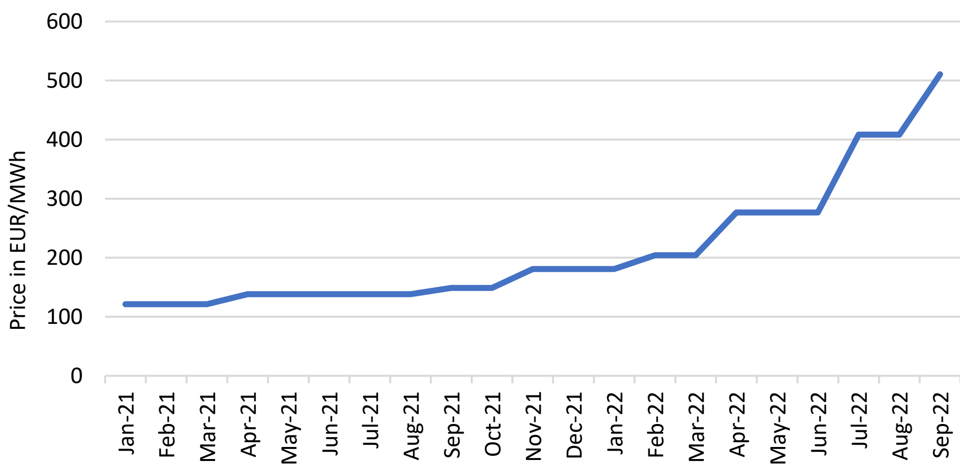

Figure 7. Business electricity rates in Poland—tariff C11 [49].

Increasing electricity prices and disrupted energy supplies in Europe motivate the EU countries to cooperate and to coordinate their policies so that fluctuations on the energy market can be minimized. European unity is vital for overcoming the energy crisis. Current electricity prices in Europe are presented in Figure 8.

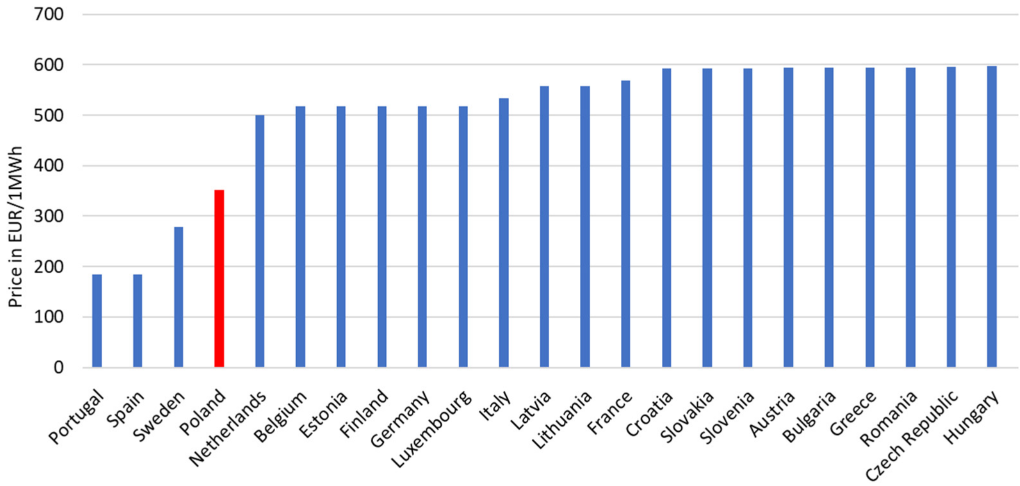

Figure 8. Electricity prices in selected EU countries (as of August 2022) [50].

The data presented in Figure 8 clearly indicate that the greatest increase in electricity prices took place in developed countries, which have the highest demand for electricity. It should also be noted that Europe had become dependent on Russian energy carriers. Therefore, the EU countries are coordinating their policies to stabilize energy supplies in the current geopolitical situation. As shown in Figure 8, Poland has one of the lowest electricity prices in Europe. Electricity prices are more than twice as high in Germany. However, a completely different picture emerges when electricity prices are compared with average incomes (Figure 9).

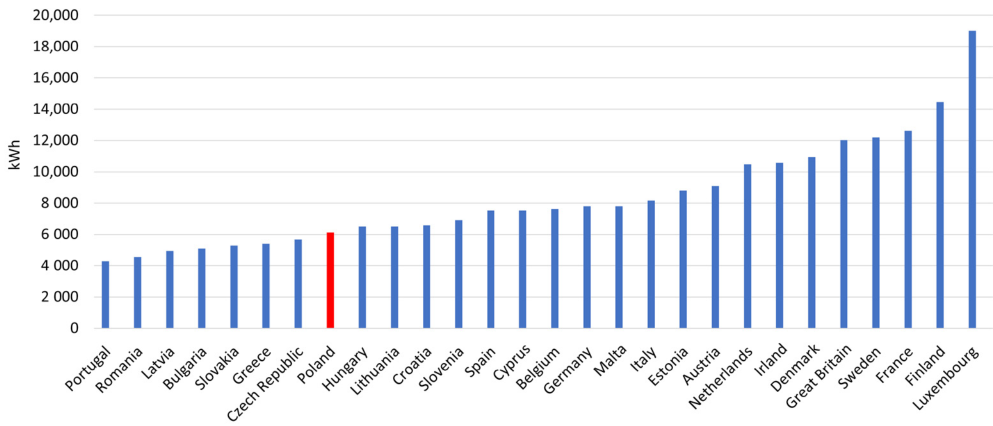

Figure 9. Affordability of electricity (in KWh) for average-income households in the EU (as of August 2022) [51].

The data in Figure 9 clearly indicate that Polish consumers spend a much higher proportion of their incomes on electricity bills than consumers in other EU countries.

In Poland, coal is a key resource in the overall energy mix. Long-term fixed-price coal contracts play a very important role in the Polish energy sector. The Polish government intervenes in the energy market to lessen the burden of high prices on consumers. A price cap was recently introduced on household electricity prices. Microbusinesses as well as small and medium-sized enterprises are entitled to an energy price cap between December 2022 and the end of 2023. These measures are only temporary, but they should assist households and businesses in coping with economic difficulties and very high inflation.

4. Discussion

Uninterrupted power supply and energy security are critical considerations that affect not only industrial and business performance, but also the quality of life of entire societies [1]. Unity among the EU countries is key to combatting the energy crisis. The high prices of imported energy can be mitigated through common purchases. In the wake of the tenuous situation on the energy market and disruptions in energy supply, the EU countries must show solidarity to break the dependence on countries that have a monopoly in the energy trade. Poland and other European countries can reduce their dependence on external energy suppliers by speeding up the transition to renewable energy. Solar power is the most effective and economically viable RES, and it can accelerate the shift to clean energy in Poland and other European countries.

The installed capacity of PV systems in the EU reached 158 GW at the end of 2021, marking an annual increase of 21.4 GW. In the EU, total installed solar capacity increased by 15% relative to 2020. In 2021, Poland was among the countries that had the greatest demand for new PV installations, which can be attributed to the dynamic growth of the solar sector in recent years. In terms of the increase in installed solar capacity, Poland ranked 8th in the EU; 27th in 2018, 5th in 2019, 4th in 2020, and 2nd in 2021, with an impressive annual increase of 3.7 GW. In May 2022, total PV installed capacity exceeded 10 GW, and Poland emerged as the seventh larger solar producer in Europe. Solar power capacity is expected to increase to 28.5 GW by 2030, which should enable Poland to remain in the European lead. However, considerable effort will be required to speed up Poland's transition to PV and other RES. Applicants seeking to connect a total of around 30 GW of renewable generation capacity to the grid were rejected between 2015 and 2021. Despite the fact that power distribution is one of the most profitable segments of the energy market, RES investments are thwarted, which obstructs Poland's transformation to clean energy [39].

In 2020, the main sources of RES in Poland were solid biofuels (71.61%), wind (10.85%), and liquid biofuels (7.79%). It should be noted that most solid biofuels were derived from plant biomass. The remaining RES sources, including biogas (2.58%), heat pumps (2.38%), solar energy (1.99%), hydrothermal energy (1.45%), waste incineration plants (1.155%), and geothermal energy (0.20%) had a marginal share of the energy market [52]. In our 2020 study [53], we observed that renewable energy sources would become increasingly prominent in global energy generation in the coming years because of the decline of the natural environment and growing energy consumption in many industries. Energy consumption is also driven by global population growth and the need to provide decent living standards around the world. According to Li et al. [33], RES development plans have to be coordinated with the performance of the energy market, and the relevant policies should be formulated in a reliable manner. Nesamalar et al. [54] observed that programs aiming to increase public awareness about RES and support schemes for research and development institutions are needed to ensure continuous progress in the RES sector.

According to Igliński et al. [55], the Polish power sector is currently facing significant challenges. The existing infrastructure for the production and transport of fuels and energy is outdated and insufficient. The emergence of new energy generation technologies and increased supply of distributed energy resources lead to problems in planning grid development and preventing transmission line overload. Ostrowska et al. (2022) [56] pointed to seasonal fluctuations in transmission line overload that are caused by differences in sunlight exposure, among other factors. However, the interest in solar energy projects increased unexpectedly in 2020 even though other RES had been predicted to develop at a faster rate. Various scenarios were discussed in the development plan for meeting the present and future demand for electricity in 2023–2032 [57] that was published in November 2022. According to the presented forecasts, the output of onshore windfarms will remain stable at around 9000–10,000 MW until 2040. The output of offshore wind farms is expected to increase significantly, from around 5000 MW in 2030 to around 8000–9000 MW in 2040. The share of solar power and gas-fired power plants in the energy mix will continue to increase. Nuclear power plants will be commissioned for use in 2035, and their combined output is estimated to reach 4000 MW by 2040. At the same time, the share of coal-fired power plants is projected to decrease to around 20% in 2040 [57].

Wind energy has a greater potential, mainly because wind farms require less land, and only small plots of farmland have to be converted to non-agricultural use. Hybrid wind and solar farms would be the optimal solution. Restrictive laws on the construction of wind farms mean that solar power remains the only viable RES in the face of the current energy crisis. In Poland, solar farms create less controversy than wind farms. However, wind farms are a better solution from the point of view of food security because they occupy less rural land that needs to be converted to non-agricultural use. Agrivoltaic farms are also an interesting solution [58–60], but in Poland, agrivoltaic projects are still in the initial phase of development. Therefore, any discussion on the prospects for RES development in Poland is presently limited to solar power. The plans to build nuclear power plants have also resurfaced in recent years, but these projects will take many years to complete (up to 10 years).

Until recently, wind power had the highest share of the renewable energy mix, but at present, the PV sector is developing more quickly. The installed capacity of all renewable energy systems in Poland currently reaches 20.9 GW. Approximately 37% of that energy is generated by wind farms and 53% is generated by PV farms (more than 11 GW) [61].

Wind farms have the greatest potential for renewable energy generation. At the end of August 2022, the total installed capacity of Polish wind farms reached 7666.3 MW, marking an increase of 12.7% from August 2021. In contrast, the installed capacity of PV farms increased by 84% in the same period [61]. Wyrobek et al. [62] analyzed the profitability of Polish wind farms in 2006–2014. During that period, only green certificates were issued to RES producers, and auctions for wind energy contracts were not held. According to the cited authors, the prices of wind energy produced in 2006–2014 had to exceed market prices in order for the farm to generate a profit. This pricing mechanism was yet another factor that contributed to the collapse of the Polish wind energy market.

To date, micro-solar installations have made the greatest contribution to the growth of the Polish PV sector. The power grid may experience technical issues, such as overvoltage, when large numbers of rooftop PV systems are connected to low-voltage (LV) distribution systems [63]. Similar observations were made by Torquato et al. [28], who observed that in areas with a high penetration of rooftop solar installations, the HC of power systems may be compromised, which can negatively affect voltage quality and lead to overvoltage and undervoltage, unbalanced voltage, and excessive loading on conductors and transformers. They also found that overvoltage poses the greatest obstacle to large-scale PV integration in distribution and transmission networks. These observations provide valuable inputs for grid operators, and they can support the development of new solutions that do not violate technical standards [28]. According to Ismaeel et al. [25], the transactive energy approach encourages the integration of various energy systems into the grid and is a promising solution for optimizing grid functionality. A number of theoretical solutions have been also proposed by Polish researchers [30]. One of them involves a large wind farm (or several dozen solar farms in various parts of the country) that would be the only source of electricity for the entire country. Such solutions play a particularly important role in Poland, which has long relied on coal-fired plants for electricity generation. The largest operators in Poland (with a high share of government ownership) recognize the need for RES development and are implementing large wind and solar power projects. Therefore, insufficient HC is a problem that affects mainly private investors.

When harmonic-injecting loads are high, or when demand-level conditions are low, grid HC may be insufficient to accommodate new PV systems. According to Kazemi-Robati et al. [64], the grid's voltage profile can be improved and distortions in the distribution system can be reduced through the use of passive filters combined with grid reconfiguration. In large solar farms, an increase in distribution network voltage can raise the farms' capacity and minimize distribution losses [65]. The continued development of renewable energy generation projects is the key prerequisite for Poland's green transformation, and it is determined by the HC of the national power grid. At present, grid HC is insufficient and constitutes the greatest barrier to implementing renewable energy projects in Poland. As a result, the national grid is unable to accommodate both large renewable power plants with a capacity of several dozen MW and small installations (less than 1 MW), regardless of the applied generation technology [38,66].

The Polish Energy Law was amended at the beginning of 2022. The new billing rules implemented on 1 April 2022 met with massive opposition from the PV industry. According to experts, the introduced changes would lead to the collapse of the PV market and would thwart the development of solar power projects. The greatest concerns were expressed by prosumers who feared that the new billing rules would make their investments in PV panels unprofitable. However, these fears proved to be largely unjustified. Although the demand for PV panels decreased markedly in the first months after the introduction of the new billing rules, this negative trend has been since reversed. The greatest increase was observed on the market of PV installations for businesses. The crisis has dramatically increased energy prices in Europe, and businesses are investing in solar panels to decrease production costs [39,48]. Luo et al. [67] analyzed technological solutions supporting heat recovery in the food processing sector to minimize food plants' energy demand. Every innovative solution is worth considering in the face of the current energy crisis.

Land requirements are a considerable problem, particularly for large-scale PV farms which need large plots of land that have been converted to non-agricultural use. Small PV installations of up to 1 MW are most popular in Poland because they are exempt from licensing requirements, and a permit is issued based on a zoning decision. Special planning permission is needed to build a solar farm on high-quality farmland (quality class I–III), and the site has to be covered by a local zoning plan. The procedure of developing a local zoning plan is long and arduous, which is why many permits have been issued based on zoning decisions in recent years [23]. The land occupied by a PV farm is generally converted to non-agricultural use for a limited period of time (usually 20–30 years). The extent to which these requirements will change in the future is difficult to predict. To date, the largest PV farms have been developed on degraded land, mostly in industrial sites (defunct brown coal mines, aggregate mines, and mineral mines that were restored) and reclaimed industrial land.

New changes are planned in Polish legislation to provide additional incentives for solar power investors. The proposed amendments will facilitate the planning process and the acquisition of PV permits. The operators of solar installations with a capacity of up to 500 kW will no longer be required to apply for an operating license based on the provisions of local zoning plans. To date, only PV farms with a capacity of up to 100 kW were exempt from the licensing requirement [23]. Solar farms located on low-quality agricultural land (quality classes V, VI, and VIz) and fallow land, PV systems with a capacity of up to 1000 kW, and installations other than ground-mounted PV panels (i.e., rooftop PV systems) will also be exempt from the licensing requirement. The grid connection process is one of the most arduous and difficult stages of investment. Similar observations were made in our previous study [23], which analyzed 95 solar project charters in different locations. A total of 10% of the projects were denied permits, and their grid connection applications were rejected. Complex administrative and legal procedures at the stage of preparing project documentation significantly obstruct the development of PV systems in Poland. According to the reports of the Energy Regulatory Office [38,45] investors are highly critical of the complex and lengthy administrative procedures for building PV farms.

5. Conclusions

The study was conducted to analyze the prospects for RES development in Poland in the wake of the energy crisis. Poland has committed to phasing out hard coal as the main energy source, but these plans have been thwarted by unforeseen events. Radical measures are needed to switch the Polish power sector to RES and break its dependence on countries that have monopolies in the energy trade. This article makes an important contribution to the discussion on speeding up RES development in Poland and increasing Poland's energy security.

The reasons for insufficient grid HC were analyzed in detail. The Polish regulatory framework poses a barrier to renewable energy development. The construction of onshore wind farms was completely blocked, and offshore wind farms are still at the planning stage. Frequent changes to the terms by which PV-generated energy is sold back to the grid also compromises the growth of the Polish PV sector.

Poland's green energy transformation was impeded by the low HC of the power grid, which forces DSOs and transmission system operators to reject applications for connecting new RES. From the technical point of view, the development of the PV sector is thwarted by insufficient HC and the poor condition of the national grid. Urgent measures are needed to modernize Poland's power infrastructure to maintain the dynamic increase in installed solar capacity. Administrative barriers for investors should be also eliminated, and new regulations should be introduced to facilitate access to the power grid. Possible solutions include direct connection of renewable energy producers to consumers, easing land requirements for the construction of new renewable energy projects (such as PV farms on agricultural land), and reducing the administrative burden on investors. Micro-solar installations can resolve these problems to a limited extent, but they are not profitable from the investors' point of view.

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