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FORECASTING THE FUTURE OF RENEWABLE ENERGY SOURCES IN POLAND AGAINST THE BACKGROUND OF THE EUROPEAN UNION STATES

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Purpose: The aim of the article is to develop a forecast for electricity generation from renewable energy sources (RES) in Poland using predictive methods based on an approximating function. The study is situated within the broader context of the energy transition and the growing importance of RES in both national and EU policy agendas.
Design/methodology/approach: The study employs a quantitative approach based on statistical data from the Central Statistics Office (GUS) for the years 2008-2024 concerning photovoltaic energy production. The primary forecasting method is a trend function, approximated and transformed into a linear form through logarithmisation. The parameters of the power function were estimated, and the accuracy of the forecast was assessed using the coefficient of determination, mean residual error, and the coefficient of variation of residuals.
Findings: The results obtained indicate a clear upward trend in photovoltaic energy production, with a projected output of 31,219 GWh by 2028. The coefficient of convergence (0.0244) demonstrates a high degree of consistency between the empirical data and the theoretical model. The findings confirm the dynamic growth of the RES sector in Poland and the increasing interest of enterprises in investing in green energy.
Research limitations/implications: The photovoltaic sector has been expanding year on year, despite facing challenges such as grid connection refusals and administrative constraints. These issues primarily affect large-scale photovoltaic farms, which are frequently curtailed by the Transmission System Operator during periods of high productivity due to the limited flexibility of the grid. Energy storage systems, when integrated with large PV installations, offer a potential solution – contributing to grid stability and ensuring reliable delivery of green energy. A limitation of the study lies in the variability of weather conditions that influence solar energy production, introducing uncertainty into the forecasts. The article highlights the need for further research on integrating forecasting models with grid management systems, as well as incorporating energy storage solutions. Future analyses could extend the model to include other renewable energy sources (such as wind or biogas).
Practical implications: The study provides forecasting tools for businesses and policymakers, supporting investment planning in the energy sector. The results may be applied in the development of long-term energy procurement strategies (e.g. Power Purchase Agreements),

grid modernisation, and the liberalisation process of the RES market. The forecasts also contribute to cost optimisation and improved energy security.
Social implications: The development of RES contributes to improved air quality and reduced greenhouse gas emissions, positively affecting public health. Promoting green energy may influence social attitudes towards climate responsibility and enhance environmental awareness. The research findings may also inform public policy in the areas of decarbonisation and climate protection.
Originality/value: The article offers original value by developing an accurate predictive model of photovoltaic energy production in Poland based on a power function. It provides practical tools for businesses, analysts, and energy policymakers, supporting the advancement of a low-emission economy. Furthermore, it constitutes a significant contribution to the literature on energy transition in both the Polish and EU contexts.
Keywords: Renewable energy; energy production; clean energy; energy security; environmental impact of energy consumption.
Category of the paper: Literature review.

1. Introduction

Renewable energy sources (RES) play a key role in achieving climate targets, ensuring energy security, and reducing greenhouse gas emissions (Beal, King, 2022). Among these, solar energy—particularly photovoltaic technology—has experienced dynamic global development, driven by declining costs and technological progress (Lewis, 2015). This study presents a forecast of photovoltaic electricity generation in Poland based on predictive modelling using an approximating function.

Given the strategic importance of energy in the economy, it constitutes a key component of many countries' economic policies. Issues such as the structure of electricity generation, sources of primary fuel supply, infrastructure investments, and energy intensity are central to energy policy formulation. However, energy policy cannot be viewed in isolation from climate policy. Today, energy and climate policy are increasingly integrated, reflecting a comprehensive approach to sustainable development. Consequently, discussions about the structure of energy generation are often linked to concerns over the continued reliance on solid fossil fuels, which are among the highest contributors to greenhouse gas emissions. Similar concerns apply to the sources of primary fuel supply.

The objective of this study is to develop a forecast for electricity generation from RES using a mechanical method and make a prediction on the basis of an approximating function. Given the inherent uncertainty related to atmospheric conditions, the analysis focuses on forecasting solar energy production.

To structure the analytical approach, the study puts forward the following hypothesis: The volume of photovoltaic electricity production in Poland follows a power trend that enables reliable forecasting for the upcoming years.

2. Literature review

In the era of sustainable development and growing energy awareness, energy efficiency in enterprises is no longer merely an advantage but a necessity. Majority of Polish small and medium-sized enterprises (SMEs) regard the transition to renewable energy as an inevitable process, with 82% of surveyed companies expressing this view. The primary benefits identified by respondents include reduced operational costs and enhanced competitiveness, as indicated by 60% of participants (Ciesielski, 2023).

Only 3% of enterprises reported that rising energy prices have had little impact on their operations. In contrast, 59% of manufacturing companies stated that the increase in energy carrier prices has significantly affected both the pricing and cost structure of their final products. Moreover, SMEs have reported experiencing power outages, with 44% considering them disruptive (Ciesielski, 2023, Energia odnawialna i konkurencyjność polskich przedsiębiorstw).

Eurostat provides comprehensive country-by-country data on energy production and consumption (Eurostat, Renewable Energy Statistics: Share of Renewable Energy More Than Doubled Between 2004 and 2021, 2022). In addition, governmental agencies and independent research institutions regularly produce energy-focused reports analysing the environmental, economic, and energy security impacts of renewable energy sources (Pacesila et al., 2016). In 2020, hydropower (about 40%) and biomass (about 30%) accounted for the largest share of electricity generation from RES within the European Union. Wind and photovoltaic energy constituted about 25% of the total renewable electricity output, while other sources and forms of energy, such as biogas, geothermal energy and wind energy made up the remaining 5%. EU member states are actively working to increase the share of RES in energy production. As part of this effort, the European Union has committed to reach a 32% share of renewable energy in gross final energy consumption by 2030 (Musiał et al., 2021).

The adoption of renewable energy sources (RES) across European Union member states shows significant variation. Countries such as Germany and Denmark have achieved shares of nearly 50%, whereas Poland and Italy remain at lower levels, ranging between 15% and 20%. These disparities are largely attributed to differences in geographic conditions, resource availability, and infrastructure development (Inês et al., 2020; Gajdzik et al., 2022).

According to the amendment to the Renewable Energy Act, the share of renewable energy in electricity generation is to increase steadily – from around 20% at present to about 38% in 2025. In 2030, it is projected to reach about 50%, in 2040 – 65%, and in 2050 – as much as 80%. Such programs and initiatives support the achievement of renewable energy targets while addressing the challenges related to climate protection and energy security (Wałachowska, Ignasiak-Szulc, 2021).

Poland, by contrast, is one of the European countries lagging behind in the drive to increase energy recovery from RES (Swain et al., 2022). Nevertheless, recent years have seen a notable increase in interest in RES, as evidenced by a growing number of investments in this sector (Suharevska, Blumberga, 2019). In 2020, the share of energy derived from RES was approximately 15%, with solar energy and biogas accounting for about 20% and 15% of RES production, respectively (Child et al., 2019, p. 80).

Italy, like Poland, is also pursuing the development of RES, but the pace remains slow. In 2020, the share of energy from RES in Italy stood at around 20%, with a primary focus on increasing energy generation from solar panels and wind turbines (Wolniak, Skotnicka-Zasadzień, 2022, p. 662).

The recovery of renewable energy contributes to reducing environmental impact by lowering emissions of harmful substances, above all, greenhouse gases. Among EU member states, the total share of RES in 2020 nearly doubled compared to 2010. The largest increases were recorded in Cyprus (from 1.4% to 12.0%), Luxembourg (from 3.8% to 13.9%), Greece (from 12.3% to 35.9%), the Netherlands (from 9.6% to 26.4%), Estonia (from 10.3% to 28.3%) and Lithuania (from 7.4% to 20.2%). In Poland, the share of electricity generated from RES rose from 2.5% in 2005 to 16.2% in 2020 (Bluszcz, Manowska, 2020).

Until recently, electricity generated from RES was much more expensive than electricity produced in power plants using fossil fuels. However, technological advancements and economies of scale have reshaped the economic landscape and improved the level of profitability. This shift is also reflected in the philosophy of business entities, for whom securing energy supplies from RES has become a cornerstone of active performance. As a result, they are now investing in solar projects or entering into long-term purchase agreements with independent suppliers (Howie, Atakhanova, 2022). At the same time, support for the idea of energy transition will transform not only the conditions for the development of individual economic sectors, but also the structure of energy markets in a sustainable direction. Nevertheless, disparities in the conditions of electricity generation and the cost of final energy are likely to exacerbate existing differences in economic and social development, and contribute to global polarisation.

3. Research methodology

The research was conducted on the basis of data from the Central Statistical Office in Poland for 2008-2024 (Bluszcz, Manowska, 2020). The linear regression model, presented in equation (1), depends on two unknown parameters, *a* and *b*. The parameters of the linear trend function were estimated using formulas (2) and (3).

$$y = at + b \tag{1}$$

$$a = \frac{\sum yt\,t - n\bar{y}\dot{t}}{\sum t^2 - n\dot{t}^2} \tag{2}$$

$$b = \bar{y} - a\,\dot{t} \tag{3}$$

When a good approximant of the trend is the power function, as defined by equation (4), linearisation should be carried out when extracting the trend using the least-square method.

$$\hat{y}t = b\,t^a \tag{4}$$

Equation (5) was obtained after both sides of the equation of the power trend function were logarithmised to express it in linear form.

$$ln\,\hat{y}t = ln\,b + a\,ln\,t \tag{5}$$

Next, a substitution was made by denoting the logarithms of the variables with the variables with asterisks (*); as illustrated in formulas (6), (7), (8).

$$ln\,\hat{y}t = \hat{y}t^* \tag{6}$$

$$ln\,b = b^* \tag{7}$$

$$ln\,t = t^* \tag{8}$$

This substitution resulted in the linearised form of the power trend function, defined by equation (9).

$$\hat{y}t^* = a\,t^* + b^* \tag{9}$$

Finally, the parameters of the power trend function were delogarithmised, as shown in formulas (10), (11).

$$a = \frac{n\sum_t y_t^* t^* - \sum_t y_t^* \sum_t t^*}{n\sum_t t^{*2} - (\sum_t t^*)^2} \tag{10}$$

$$b^* = \overline{y^*} - a\overline{t^*} \tag{11}$$

Linear regression enables the use of quantitative variables that follow a normal distribution. Four key assumptions relating to the linear regression model were considered in this study:

1. Linearity – a linear relationship between the independent variable and the dependent variable.
2. Homoskedasticity – the variance of the residuals remains constant across all observations.
3. Random parameters (of residuals) are uncorrelated and normally distributed.
4. Independence of variables – none of the independent variables can be correlated with any other independent variable.

To generate forecasts, several methods were applied: the simple moving average, the weighted moving average, the exponential smoothing model, the Holt model, and the trend function method. Among these, only the trend function method yielded precise forecasts with the smallest errors. In addition, the mean residual error, coefficient of convergence and coefficient of residual variation were calculated to test the consistency of empirical data with theoretical data (Marciniuk-Kluska, Kluska, 2023). The coefficient of convergence indicates the percentage of information not explained by the independent variable. The coefficient of residual variation reflects what percentage is accounted for by random deviations of the trend equation relative to the average level.

4. Results and discussion

Electricity, serving as the driving force behind machinery and equipment, plays a pivotal role in manufacturing processes. It enables factories to operate smoothly, efficiently, and in compliance with defined quality standards – factors that directly impact the overall productivity and performance of the enterprise.

The year 2022 marked the most expensive year on record for electricity prices on European power exchanges (Figure 1).

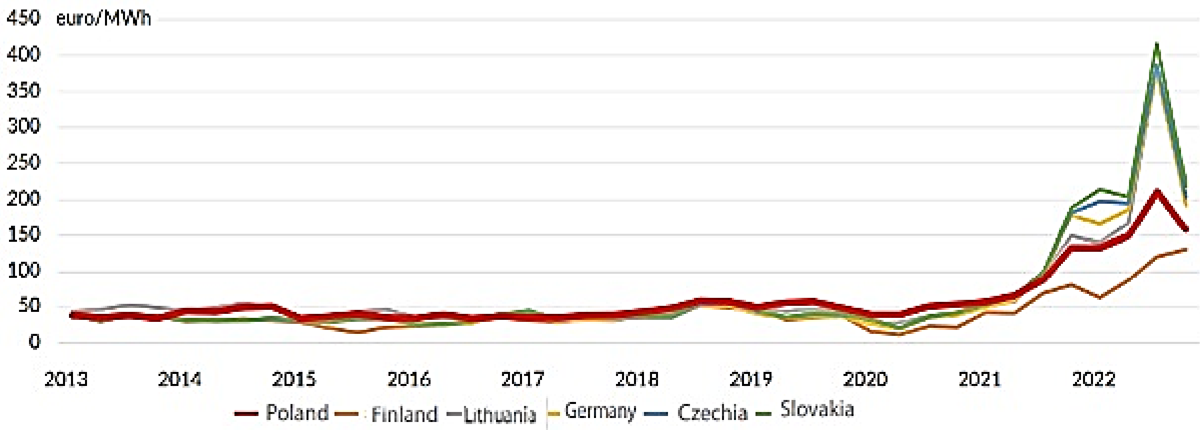

Figure 1. Comparison of SPOT electricity prices in neighbouring countries' markets in the years 2013-2022.

Source: Quarterly Report on Energy Markets, ENTSO-E, 2022.

The record-high prices in the third quarter of 2022 were caused by the tense situation within the European power systems. Additionally, a drought in France reduced electricity generation from nuclear reactors, which was already limited due to renovations. An embargo on Russian coal was imposed, and three out of four Nord Stream pipelines were destroyed. Coupled with the earlier shutdown of the Yamal gas pipeline, these developments led to a surge raw material prices on the TTF exchange, reaching over EUR 340/MWh. The decline in the prices on the electricity exchange at the end of 2022 was primarily triggered by falling natural gas prices on European exchanges, which determines electricity prices in most EU member states. With a relatively small share of gas energy in its energy mix, Poland emerged as a cheaper market than most of its neighbouring countries.

In mid-2023, over 33% of the surveyed entities used electricity generated from renewable energy sources, and 18% had such systems installed on-site. In turn, 67% of respondents declared having intelligent energy management systems. Moreover, nearly 49% of companies indicated plans to introduce renewable energy installations and digital energy consumption monitoring. High implementation costs (48%) and the lack of state support (35%) were considered to be the primary barriers to the use of renewable energy sources.

Companies in Poland can pursue one of two main pathways to adopt renewable energy: they can conclude green energy purchase agreements (PPAs) or make their own investments in the sector. PPAs reduce energy purchase costs and are long-term. This facilitates cost management, contributes to reducing carbon footprint, and eases pressure on the national power system. These contracts are popular in many countries, and the leaders in the field are: Spain, Sweden, Norway, Germany, and the UK. In Poland, however, at the end of 2021, they amounted to only 800 MW. Nonetheless, the analysis shows enormous potential. Should 34% of industrial energy consumption be sourced from renewables by the end of the decade, PPAs would need to cover 40 TWh, exceeding Poland's current total renewable energy production. But this cannot be achieved without removing barriers to emission-free energy development. Encouragingly, the number of companies using PPAs and/or investing in their own installations is growing. Biedronka, or Jeronimo Martins, serves as an example. The company concluded a long-term PPA agreement with the Swiss company GoldenPeaks Capital, as well as a separate contract to equip its stores with energy from renewable sources by 2025, reducing the consumption of traditional energy by 15 % per single location. However, the largest self-producer of electricity remains IKEA, which has, among others, a wind farm (80 turbines) and which has acquired a solar park (Grupa IKEA inwestuje w kolejne farmy wiatrowe). Similar steps have also been taken by Ciech, PolPharma, Asseco, AGD Amica, and Grupa Azoty. Without decisive action and an integrated decarbonisation policy, energy prices in Poland will decline more slowly than in other EU countries. This means that the competitiveness of Polish exports will decrease, particularly as rising labour costs in Poland affect the situation in an analogical way, and the rate of minimum wage increase is outpacing the rate of productivity growth. Therefore, there is a need to liberalise the renewable energy production market, modernise grid infrastructure, and promote enterprises' self-production of energy and the use of short direct transmission lines. In parallel, there is a need to popularise clean energy purchases under long-term PPAs and implement technologies that optimise energy consumption. In the years ahead, a completely new allocation of work is expected across the European market. Leading positions will be secured by economies that employ new technologies that enable the production and use of low-emission energy in their industrial processes.

The data for selected EU countries presented in Figure 2 shows an increase in the share of renewable energy in final energy consumption in 2020 compared to 2017.

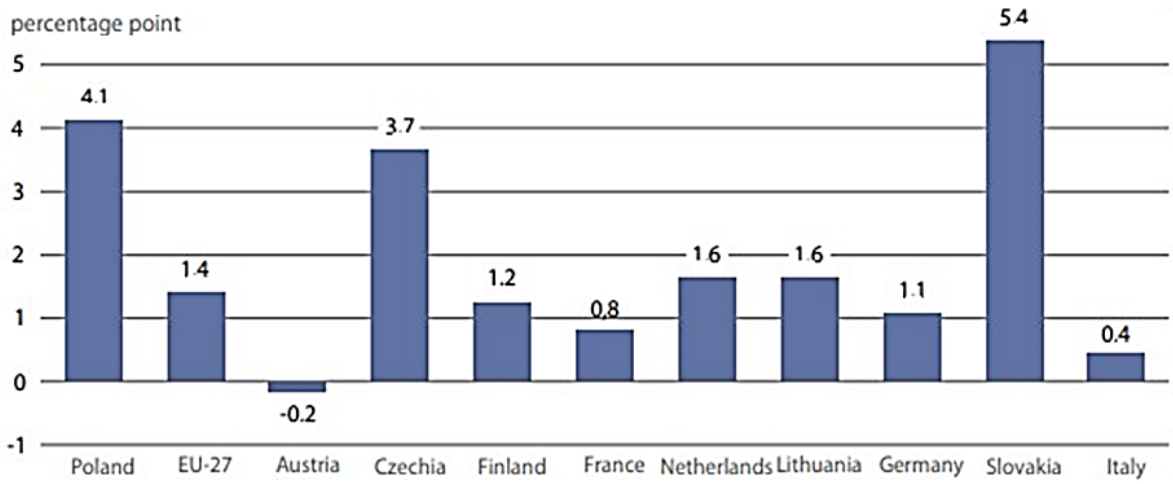

Figure 2 Growth rate of the share of renewable energy in final energy consumption in 2020 (compared to 2017).

Source: Environmental Protection in 2021, CSO, Warsaw 2022.

The largest increase in the share of renewable energy in final energy consumption were recorded in Slovakia (5.4 pp), Poland (4.1 pp), and the Czech Republic (3.7 pp). In contrast, a decrease was observed only in Austria (of 0.2 pp). Across the EU–27, the increase amounted to 1.4 pp. The national targets for the share of energy from renewable sources in gross final energy consumption in 2020 were aligned with European Parliament and Council Directive (EU) 2018/2001 of 11 December 2018 on the promotion and use of RES.

Poland has recently witnesses a substantial rise in the total installed capacity of power plants using RES. According to the Energy Regulatory Office (ERO) data, halfway through 2018, the installed capacity of photovoltaic power plants was 110.563 MW (602 photovoltaic installations). In 2019, there was an increase in the installed capacity, especially in photovoltaic power plants, reaching 478 MW, and wind power plants, reaching 5.917 GW (Energetyka Dystrybucja i Przesył). The draft Energy Policy of Poland until 2040 assumes a further increase in the share of RES in gross final energy consumption to at least 23% in 2030 (Miłek et al., 2022, p. 5576). Starting in 2025, offshore wind power is to be additionally developed, reaching about 5.9 GW (in 2030) and 8-11 GW (in 2040). Currently, RES meets about 16% of energy demand (an increase of 2.5% compared to 2018) (Rybak et al., 2022, Energetyka Dystrybucja i Przesył).

Among renewable sources, solar energy holds particular significance and is considered one of the most abundant and important energy resources on Earth. Solar energy can be converted into heat in solar collectors (photothermal conversion) and used to produce electricity using photovoltaic cells relying on semiconducting properties of silicon (photovoltaic conversion, Figure 3).

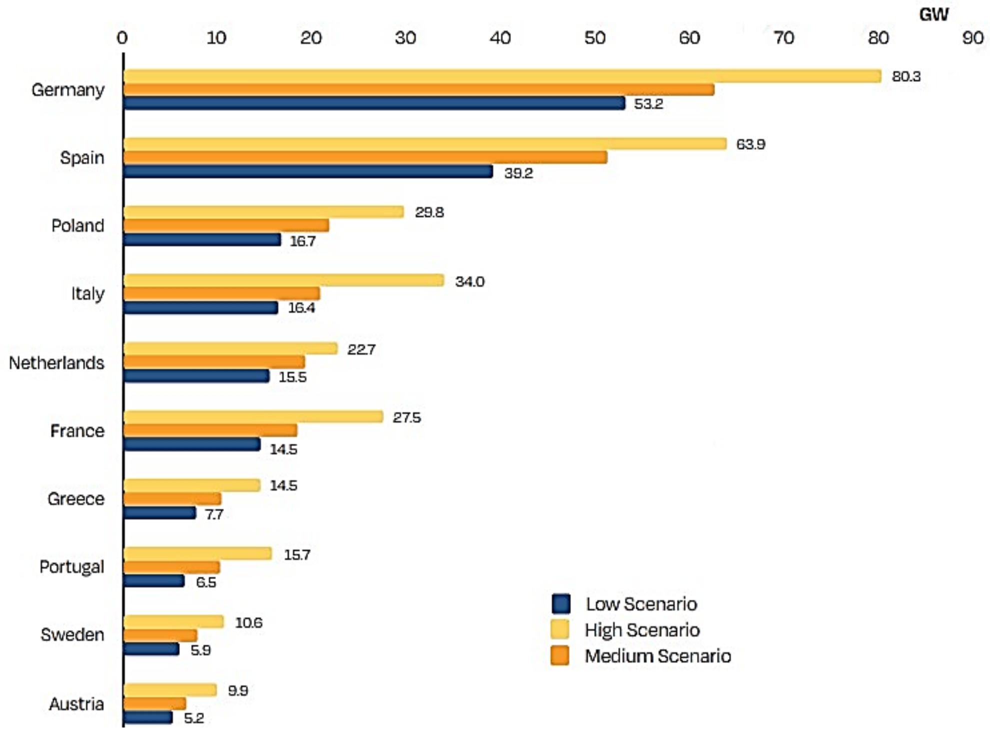

Figure 3. EU-27 top 10 solar PV markets additions 2023-2026.

Source: SolarPower Europe, 2022.

Another solution is the conversion of solar energy into chemical energy, known as photochemical conversion. This process occurs in green plants and is called photosynthesis. Solar energy is used on a large scale in solar power plants. In 2020, the world leaders in the use of solar energy were the Netherlands (26.2%), Italy, and Germany (Figure 4).

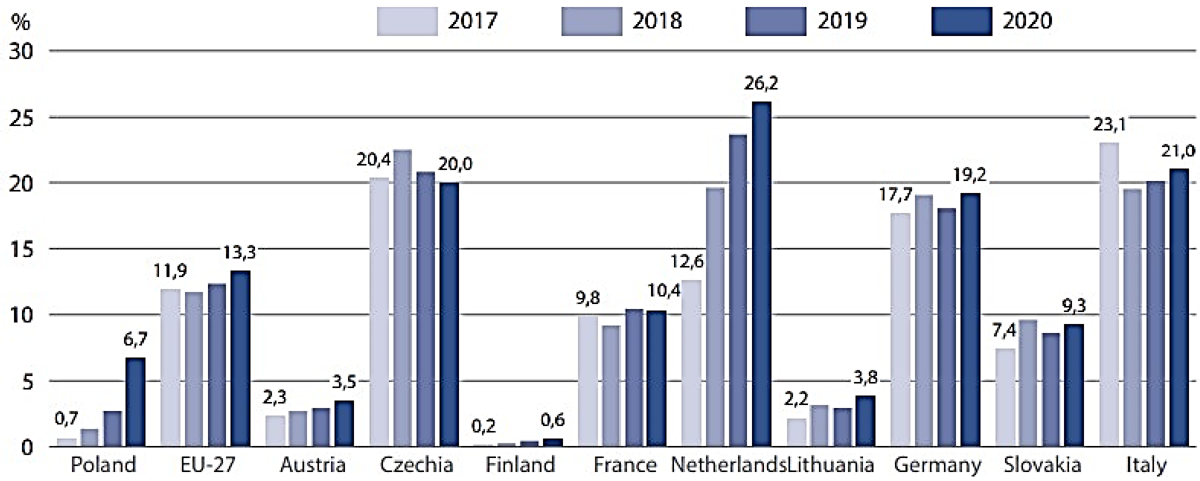

Figure 4. Share of solar energy in the production of electricity from renewable sources in Poland and selected EU–27 member states.

Source: Renewable energy in 2021, CSO, Warsaw 2022.

One of the European Union's goals for the development of renewable energy is to increase the share of electricity generated from RES in gross final consumption of electricity (Figure 5).

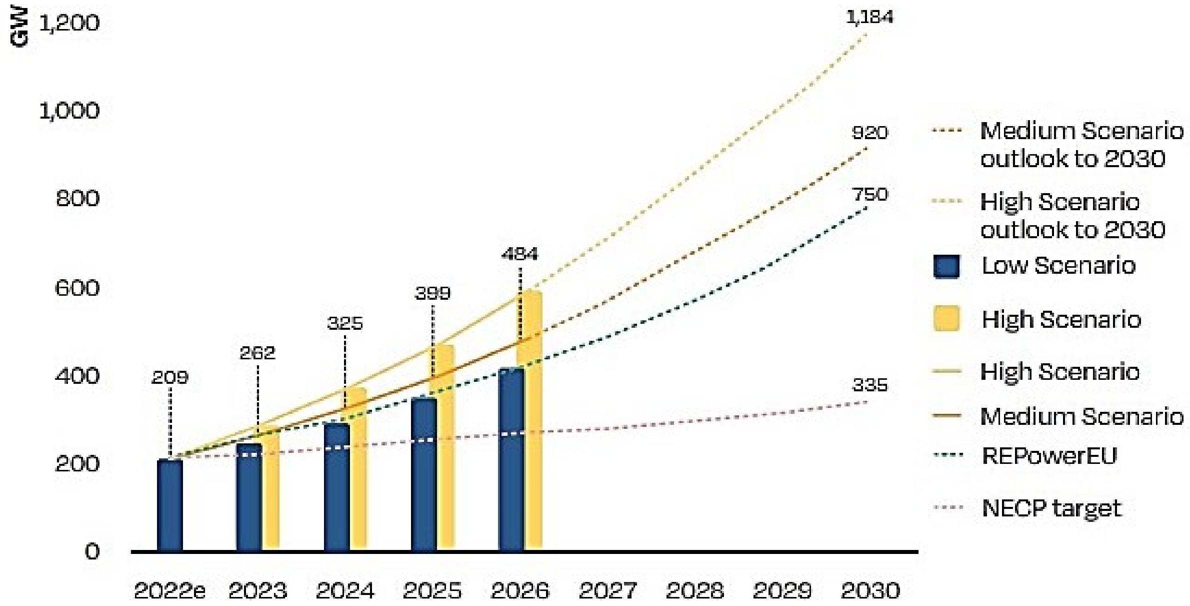

Figure 5. EU-27 total solar PV market scenarios 2022-2030.

Source: Solar Power Europe, 2022.

According to the medium scenario projection shown in Figure 6, the total amount of solar energy in the EU is expected to rise from 209 GW installed at the end of 2022 to approximately 920 GW in 2030. The increase in energy obtained through PV is particularly important in the context of reducing energy demand within the total energy balance. The value of this indicator for Poland in 2017-2020 increased from 14.4% to 18.4%. The primary factor influencing the energy production of photovoltaic panels is insolation. As illustrated in Figure 7, insolation levels vary considerably across Europe. The highest values are found in southern countries, namely Spain, Portugal, Italy, and Greece.

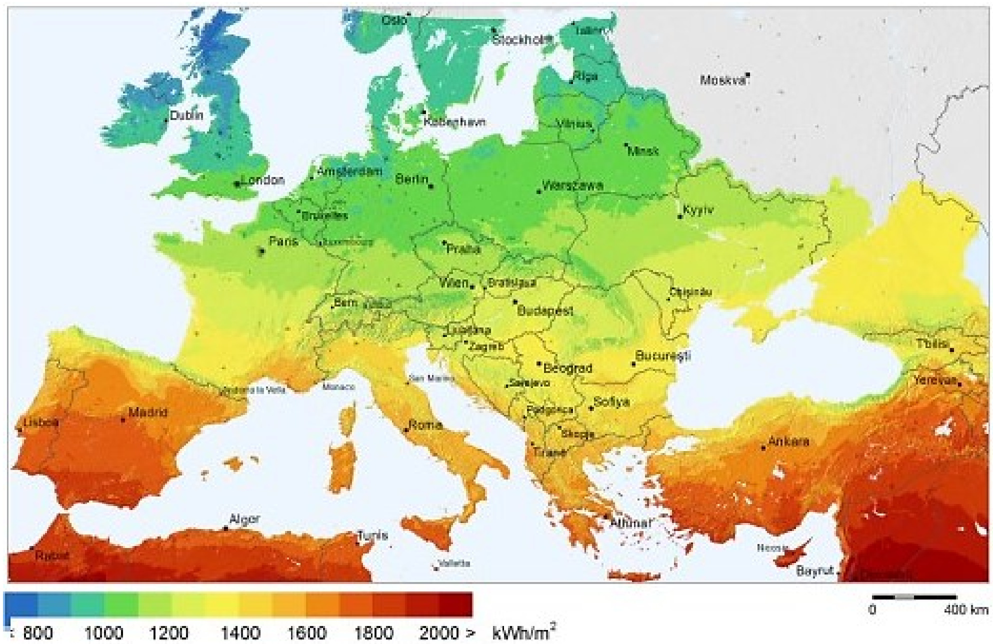

Figure 6. Annual map of average insolation in Europe.

Source: Clean Energy Project, Słupsk 2020.

In Poland, insolation varies by region, between 949 and 1168 kWh/m^2, while in Greece it is considerably higher, ranging from 1168 to 1899 kWh/m^2. Similarly, energy capacity in Poland is lower (949-1168 kWh/kWp) compared to energy yield in Greece, where it ranges from 1314 to 1753 kWh/kWp.

Renewable energy is currently one of the most rapidly developing segments of the energy sector in Poland. Owing to the country's diversity in terms of geological, climatic and hydrological conditions, it is possible to utilise diverse resources, creating a balanced energy supply system based on RES. According to Bloomberg New Energy Finance (New Energy Outlook 2024), by 2050 half of energy will be produced from wind or sun. This transformation will be driven by significant cost reductions – up to 71% for photovoltaic (PV) installations and up to 58% for wind energy. Between 2017 and 2021, electricity generation from RES showed a steady upward trend, except for 2018 when there was a decrease by 14.15% compared to 2017 caused by a fall in the production of wind power. Despite this decline, the volume of wind power generation in 2021, compared to 2017, was 8.9% higher (an increase from 14,909 GWh to 16,233.5 GWh). The photovoltaic power generation has recently gone up. In 2021, it was 100.9% higher than in 2020, and more than 23.7 times higher than in 2017.

Currently, transmission and distribution system operators are facing a growing problem of maintaining a supply-demand balance. This is due to the growing share of RES power plants in the overall energy mix. With the development of RES, it is necessary to develop tools to support operators in the efficient management of the network. These tools include forecasting models of energy production from renewable energy power plants. Issues relating to the forecasting of energy production volumes, especially in photovoltaic power plants, have recently come to the fore.

To approximate the development trend of photovoltaic electricity production (in GWh) over time, it was assumed that the development trend is non-linear. In Poland, the production of electricity from photovoltaic cells has shown a markedly upward development trend during the period analysed. The annual growth rate in energy production using photovoltaic cells has been increasing. It can be hypothesised that a power function serves as a good approximant for the trend. Linearisation was carried out when extracting the trend using the least square method (Table 1).

Table 1.
Supporting calculations for determining the parameters of the power function representing the trend in photovoltaic electricity production (in GWh) for the period 2013-2024

t	y_t	ln t	$\ln y_t$	$\ln y_t$ lnt	$(\ln t)^2$	$yt_{teor.}$	$(vt\text{-}vt_{teor})^2$	$(vt\text{-}vt_{śr})^2$
1	1	0.000	0.000	0.000	0.000	1	0	11793501
2	7	0.693	1.946	1.349	0.480	9	3	11752327
3	57	1.099	4.043	4.442	1.207	43	187	11412010
4	124	1.386	4.820	6.682	1.922	134	104	10963825
5	165	1.609	5.106	8.218	2.590	323	24841	10693990
6	300	1.792	5.704	1.220	3.210	661	130032	9829270
7	711	1.946	6.567	1.778	3.787	1211	249893	7421084

Cont. table 1.

8	1958	2.079	7.580	1.761	4.324	2047	7883	2182021
9	3934	2.197	8.277	1.187	4.828	3252	465103	248835
10	8309	2.303	9.025	2.781	5.302	4921	11480703	23754251
11	11107	2.398	9.315	2.337	5.750	7157	15601344	58857027
12	14549	2.485	9,585	23.819	6.175	10076	20008026	123517291
∑78	∑41 222	∑19.987	∑71.68	∑144.574	∑39.575	∑29 833	∑47968117	∑282425432

Source: own study.

Projections for photovoltaic energy production have shown exponential growth in the subsequent years and are expected to reach 31,219 GWh by 2028 (Figure 7).

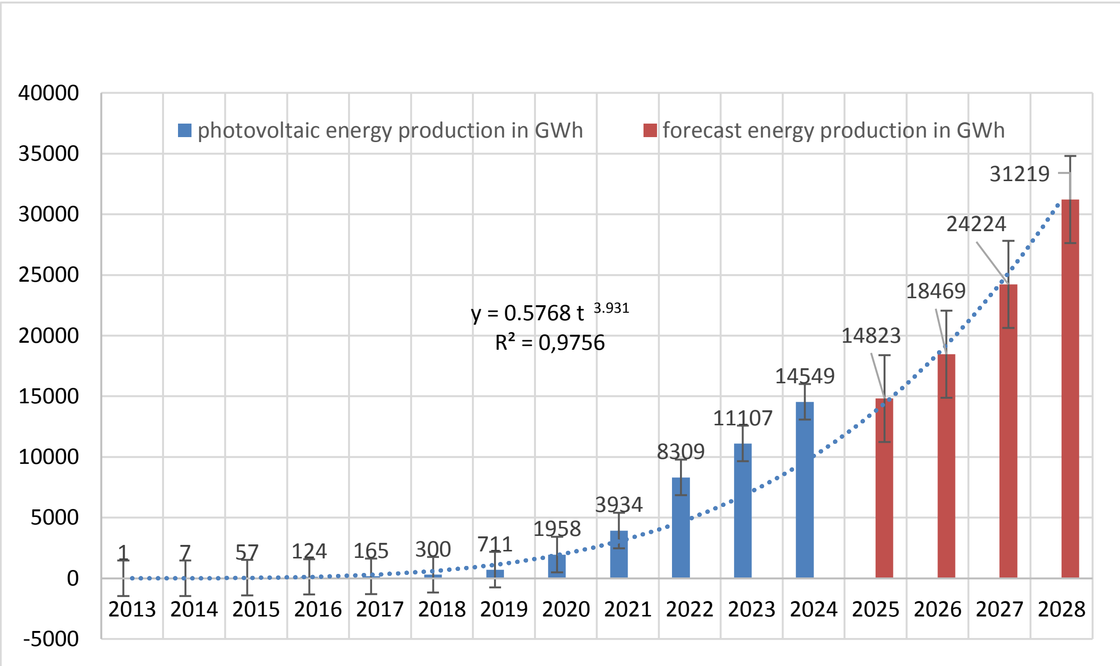

Figure 7. Projections of photovoltaic electricity generation for the period 2013-2028 (in GWh).

Source: own compilation based on data from CSO, Renewable Energy 2014-2022.

The calculated coefficient of convergence indicates that only 0.024% of the variance in photovoltaic energy production remained unexplained by the independent variable (Table 2).

Table 2.

Forecasts and forecast errors of photovoltaic electricity production by 2028 (in GWh)

Years	Photovoltaic electricity production forecasts	Convergence factor φ^2	Average error of residuals	Residual variation factor %
2025	14 823	0.0244	219.0	0.6376
2026	18 469			
2027	24 224			
2028	31 219			

Source: own study.

The standard deviation of the residuals indicates that the average deviation of the empirical values of energy production from the theoretical values determined from the trend equation is 2.81 GWh.

5. Conclusions

Many global exporters – both countries and enterprises – are increasingly aware that green energy may alter their position in the global economy, as the European Union is introducing a carbon border adjustment mechanism which will impose levies on goods generating a carbon footprint. This development will significantly worsen the competitive conditions of competition in the EU market for products manufactures using fossil fuels. It is one of the key drivers behind China's implementation of energy transition policies, as the world's largest exporter. Climate commitments by global corporations are not solely motivated by regulatory pressures. More than 34% of the world's largest companies have already pledged to achieve net zero emissions by 2050. However, most of them are unlikely to meet this commitment if they do not double the rate of emissions reduction by 2030. According to the International Energy Agency, approximately 60% of gross revenues in the technology sector are generated by companies that have declared climate neutrality as a strategic objective. In other sectors, such commitments account for 30-40% of operations in aviation and maritime transport, 15% in logistics, and 10% in the construction industry. Achieving net zero emissions necessitates the adoption of smart technologies for monitoring emissions across the entire value chain (including both direct and indirect emissions) and the integration of ESG indicators into companies' core operational and strategic goals.

The findings of this study confirm the dynamic development of the renewable energy sector in Poland, particularly in the field of photovoltaics, and highlight the need to intensify efforts supporting the ongoing energy transition. To enhance the effectiveness of RES deployment and meet climate and economic challenges, a set of strategic recommendations is proposed for key stakeholder groups.

Transmission and distribution system operators (TSO/DSO) must prioritise the modernisation and expansion of energy infrastructure to accommodate the increasing share of RES in the energy mix. This involves improving network capacity, implementing smart substations, and decentralising transmission systems. Furthermore, advanced forecasting models based on artificial intelligence and machine learning should be deployed to optimise the prediction of both production and demand, ensuring grid stability. The integration of energy storage systems—including stationary batteries, pumped-storage power stations, and hybrid solutions—can provide a buffer during peak demand or reduced production. In parallel, simplified access for prosumers to the electricity grid is essential, requiring streamlined connection procedures and transparent administrative frameworks.

Businesses and energy sector investors are encouraged to develop in-house RES installations and hybrid systems (e.g. PV combined with storage) to reduce operational costs, increase energy independence, and fulfil ESG commitments. The adoption of long-term Power Purchase Agreements (PPAs), particularly within energy clusters or cooperatives, offers price stability and supports strategic planning. Additionally, digital Energy Management Systems (EMS) should be implemented to optimise energy usage in real-time, improving efficiency and competitiveness. Diversification of the RES portfolio beyond photovoltaics—by incorporating wind, biogas, or biomass—can mitigate seasonality-related risks and enhance reliability.

Public authorities and policymakers play a critical role in shaping a conducive environment for RES expansion. Streamlining administrative procedures through digital platforms and "one-stop shops" can accelerate project approvals and grid connections. Increased access to public funding—through EU mechanisms, the National Recovery Plan, or climate funds—should support both preparatory and investment stages of RES projects. A comprehensive national energy storage strategy is also needed, encompassing ownership regulations, grid services, and financial incentives. Moreover, collaboration between academic institutions and industry, along with vocational training programmes, is necessary to address the growing demand for skilled professionals in the renewable energy sector.

For society and individual consumers, awareness-raising campaigns should be implemented at all levels—from school education to media initiatives—to foster social acceptance and engagement in the energy transition. Support for individual prosumers must also be reinforced through financial incentives, simplified installation procedures, and stable billing mechanisms (such as net metering or net billing). Finally, ensuring equitable access to clean energy is essential. Targeted programmes for low-income households, rural areas, and peripheral regions (e.g. energy communities) can help prevent energy exclusion.

In summary, Poland's energy transition is an inevitable process requiring a coordinated, multi-actor approach. The proposed actions serve as a roadmap for fostering the development of renewable energy sources while enhancing economic competitiveness, energy security, and climate protection.

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