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ENERGY TRANSITION - THE CHALLENGES FOR POLAND VERSUS THE EXPERIENCE OF EU MEMBER STATES

TRANSFORMACJA ENERGETYCZNA - WYZWANIA DLA POLSKI WOBEC DOŚWIADCZEŃ KRAJÓW UE

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Abstract: Energy security is essential for Poland's economy, society and sovereignty. Its essence is to provide continuous access to energy, the amount of which is sufficient to meet our country's needs regardless of possible disruptions or threats. The consequences of the war that Russia started in 2022 have reached far beyond the borders of Ukraine. Energy prices all over Europe have significantly increased, thus clearly showing that much more green energy needs to be produced. Renewable energy sources, including wind energy, are playing an important and positive role in curbing the energy price rise, which would have been even stronger had it not been for wind energy. The purpose of the paper is to prepare a forecast on the energy production from renewable energy sources with the use of predictive models based on function approximation. Wind energy production is uncertain and depends, among others, on atmospheric factors, such as the wind power. The conditions for generating electric energy and the price of final energy may deepen the discrepancies between the social and economic development of countries and contribute to the polarisation of the world.
Keywords: renewable energy, energy production, clean energy, energy security, environmental impact of energy consumption

Streszczenie: Bezpieczeństwo energetyczne jest podstawą naszego kraju i jest niezbędne dla naszej gospodarki, społeczeństwa i suwerenności. Jego istotą jest zapewnienie ciągłego dostępu do energii w ilości wystarczającej do zaspokojenia potrzeb naszego kraju, niezależnie od ewentualnych zakłóceń i zagrożeń. Konsekwencje działań wojennych rozpoczętych przez Rosję w 2022 roku sięgają daleko poza granicę Ukrainy. Ceny energii w całej Europie znacząco wzrosły i wyraźnie pokazały, że należy wyprodukować znacznie więcej zielonej energii. Odnawialne źródła energii, w tym energia wiatrowa, odegrały ważną i pozytywną rolę w ograniczeniu wzrostu cen energii. Celem artykułu jest przygotowanie prognozy produkcji energii z odnawialnych źródeł energii z wykorzystaniem modeli predykcyjnych opartych na aproksymacji funkcyjnej. Produkcja energii wiatrowej jest niepewna i w dużym stopniu uzależniona m.in. od czynników atmosferycznych, takich jak siła wiatru. Warunki wytwarzania energii elektrycznej oraz cena energii końcowej mogą pogłębiać rozbieżności w rozwoju społeczno-gospodarczym krajów i przyczyniać się do polaryzacji świata.
Słowa kluczowe: energia odnawialna, produkcja energii, czysta energia, bezpieczeństwo energetyczne, wpływ zużycia energii na środowisko

Introduction

The power industry plays a key role in developing countries and providing citizenries with comfortable lives. Facing the challenges connected with climate change, environmental pollution and a growing dependence on fossil fuels, the energy transition has become one of the most important topics on the international stage. As a member of the European Union, Poland needs to adjust its own energy sector to the common goals for CO^2 emissions and to increase the share of renewable energy sources in the energy mix.

With the global challenges connected with environmental protection, climate change and shaping a sustainable energy future, the energy sector transformation towards more ecological and sustainable energy sources has become an indispensable component of our future. Nonetheless, at the same time, one cannot forget about the vital aspect of national security, that is, energy security.

Appropriately planned actions in line with specific conditions and needs will help to attain a balance between the ecological goals and energy security, protecting sovereignty and development.

Literature review

In the past few years, the energy transition has become one of the key topics on the international stage, and Poland, as a member of the European Union stands before exceptional challenges and opportunities in the scope of adjusting its own energy sector to the new reality. Renewable energy sources are a key issue in the world today in the context of fighting climate change and curbing greenhouse gas emissions. One of the most essential aspects of that transition is the development of renewable energy sources, including wind energy, obtained through wind turbines and converted to electricity (Tyler, Beiter, Duffy, 2020, 2019). The largest investments in the development of that technology and the construction of offshore or onshore wind farms are in Denmark, the Netherlands and Italy (Brodny, Tutak, 2020, p. 913).

Hydropower, derived from the movement of water, which is converted to electricity using hydroelectric turbines, is also becoming widely used. Hydropower plants are among the most efficient and reliable sources of electricity (Tyler, Beiter, Duffy, 2020, 2019). They are most popular in Norway, Canada and Switzerland. Yet another form of RES is geothermal energy taken from magma in the Earth's core and geothermal rock energy (Famulska, Kaczmarzyk, Grząba-Włoszek, 2022, p. 8718). Geothermal energy is used in various countries around the world, including Iceland and Kenya (Bajan, Łukasiewicz, Mrówczyńska-Kamińska, 2021, p. 3945). A different type of energy is biomass energy, which comes from organic material such as wood, straw, agricultural wastes and biologically decomposing garbage (Gavrilescu, 2008, p. 538).

A promising renewable form of energy is marine power. Its generation is based on the natural phenomena of tides, currents and air movements over the sea surface (Bryden, Couch, 2006, 133, Harrison, Wallace, 2005, p. 1801).

The aforementioned RES are crucial because they are helping to reduce the dependence on conventional energy sources such as oil, coal and natural gas. Additionally, they support environment protection by reducing the emissions of greenhouse gases and other harmful pollutants.

Many EU member states have developed their own strategies and plans (Rakowska, Ozimek, 2021, p. 2765; Ohlhorst, 2015, p. 307) to facilitate the development of RES, including investing in infrastructure, subsidising projects and granting access to relevant technologies. Supporting the growth of RES is crucial mainly for reasons concerning EU energy security and natural environment improvement (Sinsel, Riemke, Hoffmann, 2020, 2271), Larsson, Elofsson, Sterner, Åkerman, 2019, 788, Elmassah, Biltagy, Gamal, 2022, pp. 320, 321, 337, 338).

One country that has seen significant progress in the field is Denmark. Denmark has more than 55% of its energy coming from RES (Chart 1): it is the leader in wind energy production and the leader in renewable energy in Europe and one of the countries with the largest share of renewable energy in the energy mix (Sovacool, Brown, 2010, p. 94). Denmark is one of the states with the most wind turbines in the world.

The energy they produce accounts for more than 40% of Danish electricity production (Mendonça, Lacey, Hvelplund, 2009, p. 384; Oteman, Wiering, Helderman, 2014, p. 12). Denmark, similarly to Germany, conducts extensive educational and promotional campaigns for renewable energy recovery in order to raise public awareness and generate involvement. The country is involved in the cooperation in the field of renewable energy, including the exchange of expertise and best practices, with other states across the globe. Such activities allow Denmark to remain at the forefront of the countries with the highest share of RES and the pursuit of their climate and energy security goals (Belkin, 2008, 76).

Poland's major focus is on the development of energy production from wind turbines and biomass (Stec, Grzebyk 2022, 8278.) In recent years, the number of wind and photovoltaic installations has increased, and new technologies for the use of biogas and solar energy have been developed (Safarzynska, Bergh, 2011, p. 6440). In Poland, wind energy accounts for the largest share of electricity generation from RES, making up about 40% of all RES (Rokicki, Perkowska, 2021, 1098). Hydropower and biomass are also vital sources of renewable energy in Poland, but their share is much smaller than that of wind and solar power (Chudy-Laskowska, Pisula, 2022, p. 7369). Even though Poland has recently seen an increase in the number of wind farms and photovoltaic installations, which have boosted the share of RES in the country's energy mix (Kacperska, Łukasiewicz, Pietrzak, 2021, p. 5680), it continues to report one of the lowest RES levels in Europe.

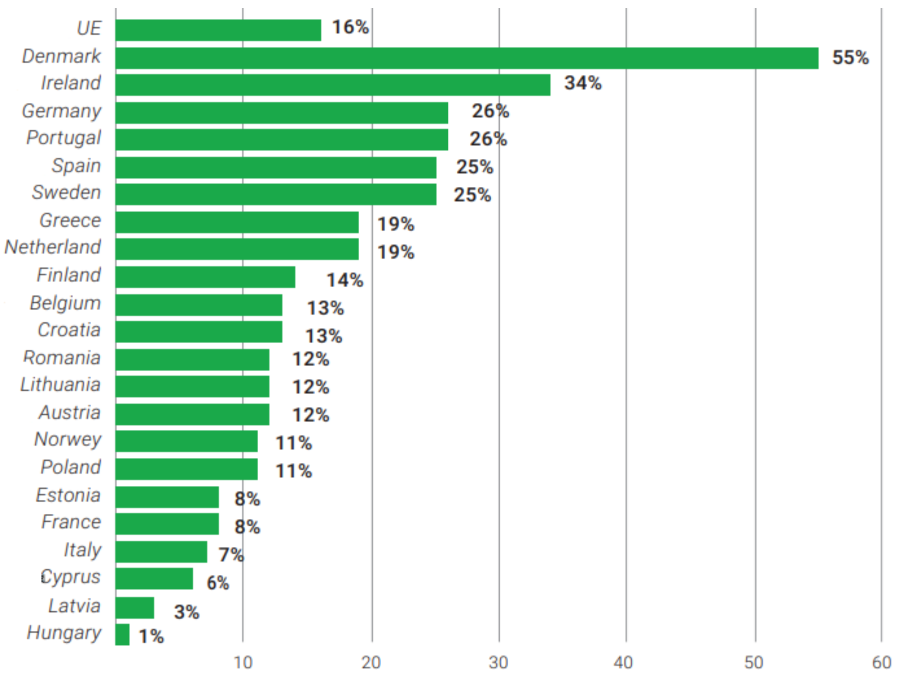

Chart 1. Percentage coverage of energy demand from wind power in selected European countries

Source: WindEurope

Bulgaria focuses on extending energy production from wind turbines and biomass. The country has many projects and investments in this area, and a lot of new wind farms and biogas plants are being built to increase the share of RES (Zdonek, Tokarski, Mularczyk, 2022, p. 846).

Despite the specified investments, a number of challenges remain and the development of RES is slow. Many existing installations need to be upgraded, and the infrastructure necessary to develop the industry is still imperfect. Accelerating the development of RES in Eastern European countries to approximate the EU's renewable energy targets requires additional investments and actions.

Some countries have also taken formal initiatives for the development of RES. It may be exemplified by the European Union, whose policy is to develop green energy. In 2018, the Union adopted new rules on renewable energy sources. They set a new, higher target for the member states regarding the share of RES in total energy production by 2030. They also imposed an obligation to introduce many facilitations for the development of renewable sources, including the expanded activities of prosumers and energy communities (Search results – Publications Office of the EU europa.eu (https://www.statista.com/statistics/561888/global-daily-oil-demand-by-region-due-to-covid-19 [access: 18.12.2023]).

Onshore wind power is the cheapest source of energy. Each additional gigawatt of wind farm capacity means real savings of about PLN 30 on the average cost of generating 1 MWh in the country (Chart 2). According to the Energy Market Agency, the installed capacity of wind farms amounted to nearly 8.4 GW last year. More than 22% of total electricity generation in 2022 came from renewable energy sources. The best result was achieved by wind power with a 10.8% share in the energy mix.

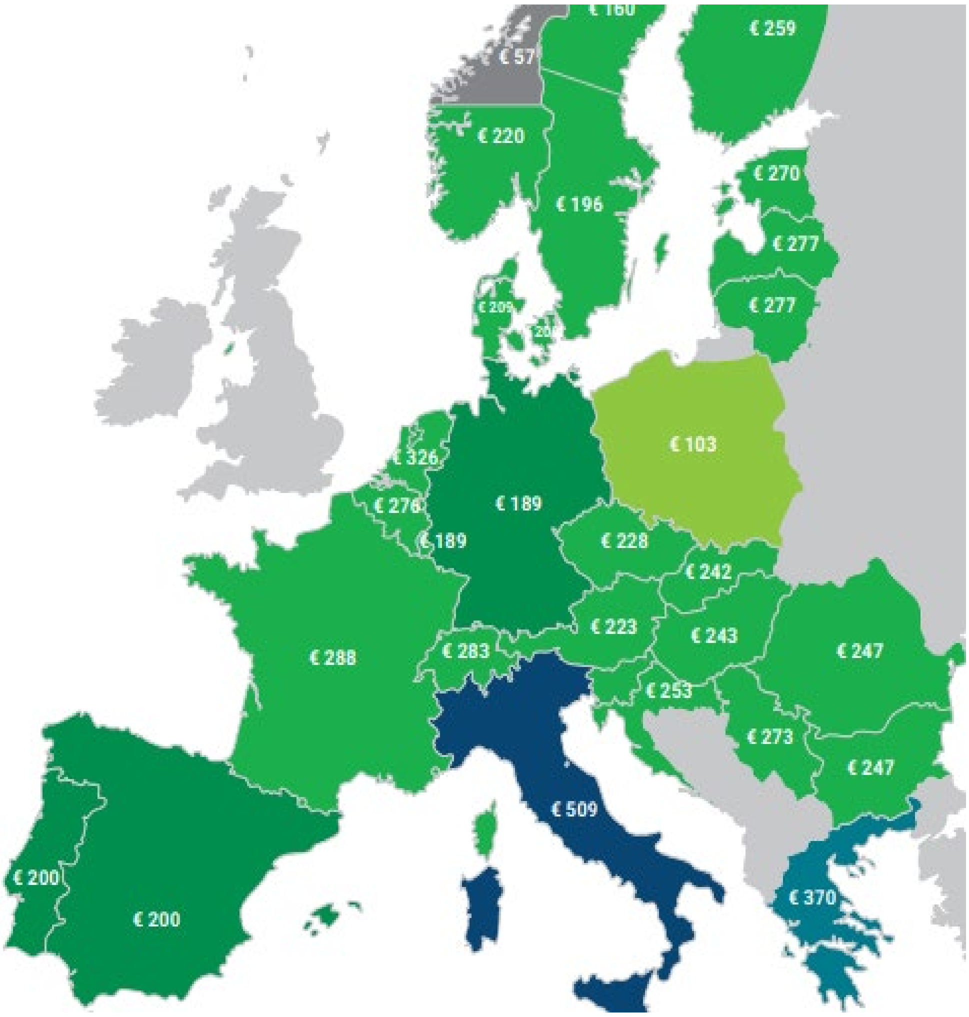

Chart 2. Average electricity prices [in EUR]in Europe, 2022.

Source: Wind energy in Poland, Report 2023.

Contemporary considerations about energy markets indicate a significant change in the philosophy of their perception. Energy produced from renewable energy sources plays an increasingly important role, and their use is also accompanied by the development of technology, scientific progress as well as the development of public awareness. A widespread use of RES as a source of primary energy is not only an element of diversification of energy carriers, or the creation of energy security, but an impulse for economic development (Açar, Öz, 2020, p. 481-487; Kastanaki, Giannis, 2022, p. 1-13; Khan, Ibrahim, Al-Amin, Yu, 2022, p. 4415; Łukasiewicz, Pietrzak, Kraciuk, Kacperska, Cieciora, 2022, p. 82-84).

Highly developed countries will take advantage of differences in the prices of both primary and secondary energy and in response will make geographical changes for the location of energy-absorbent activities. As a consequence, we will get a new picture of the world, were countries with a higher level of development will record low levels of CO_2 emissions and in underdeveloped countries there will be an increase in emissions of harmful substances into the atmosphere. These countries will remain a place of waste storage and the location of environmentally burdensome production activities (Martins, Felgueiras, Smitkova, Caetano, 2019, p. 964; Wolde-Rufael, Weldemeskel, 2020, p. 568-582; Salami, Kordi, Bolouri, Delangiz, Lajayer, 2021, p. 1349-1365).

In 2022, there were 80 new installations with a total capacity of 935.84 MW. Compared to December 2021, the volume has increased by 16% (Chart 3).

Onshore wind power continuously contributes to a decline in electricity prices. Thanks to wind turbines, average wholesale electricity prices in early October 2022 were among the lowest in Europe – 503 PLN/MWh at the time, helped by favourable wind conditions, among other factors. Generation from wind farms can cover more than 40% of the energy demand for the morning time, and the high reserve allows for energy exports.

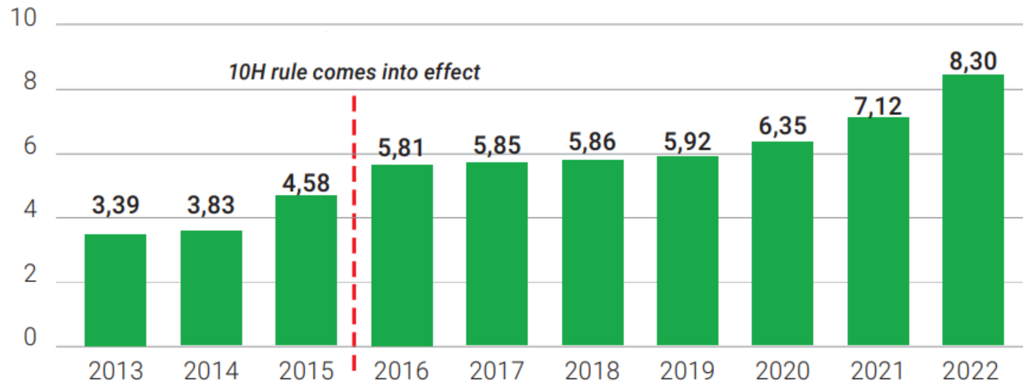

Chart 3. New onshore plants in Poland between 2013 and 2022 [GW]

Source: URE, ARE, PSEW

New wind installations in Europe in 2022 totaled 19 GW, with 17 GW of onshore capacity and 2 GW offshore. EU member states accounted for 16.1 GW of new plants (Chart 4).

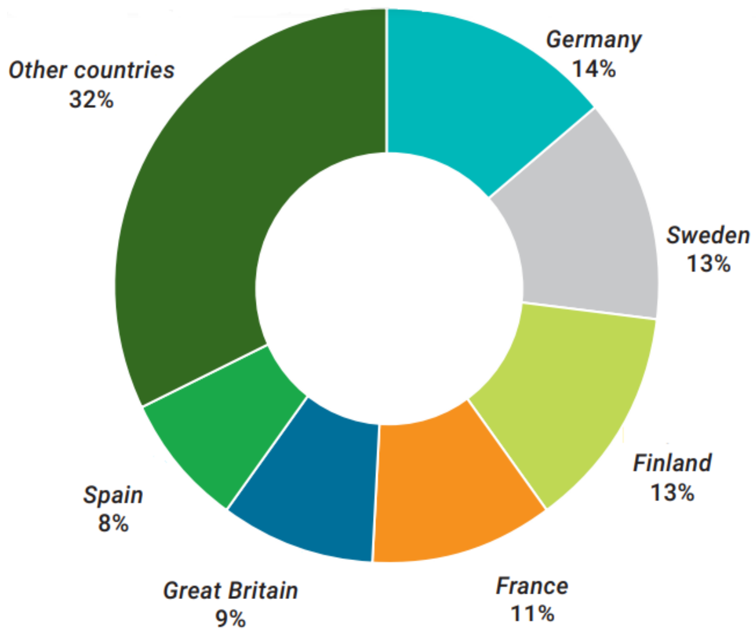

Chart 4. Percentage of new wind installations in Europe by country in 2022

Source: WindEurope

Over the past decade, total installed capacity in Europe has increased from 121 GW in 2013 to 255 GW in 2022. The average rate of construction of new wind farms during this period was therefore 10 GW per year. Europe is expected to install 129 GW of new wind farms between 2023 and 2027, and of that, 98 GW in the EU alone. Three-quarters of the new capacity between 2023 and 2027 will be in the onshore sector. The EU aims to build an average of 20 GW of new wind farms per year between.

Research methodology

The assessment of the parameters of a statistical model from the data is called an estimation, while the estimates of these parameters are called estimators. The estimators of the parameters a and b were carefully selected to obtain a straight line that matched the observations best. The linear approximation is subject to an error (of approximation) for each pair (t_i, y_i), so methods to minimise these errors were used. The observed values of trait y_i, i = 1, 2, ..., n were compared with the theoretical values of $\hat{y}_i$ obtained from used to estimate parameters a and b. The values of y_i and $\hat{y}_i$ should differ from each other as little as possible, and the differences between them should be as close to zero as possible. However, the residuals can also be positive or negative (rarely equal to zero), so the sum of all residuals can be equal to 0 even if the individual residuals are not close to zero. Thus, one can consider the squares of the residuals instead of the residuals, as squares have the advantage of being non-negative. Residuals close to zero make their squares $(y_i - \hat{y}_i)^2$ smaller and smaller.

When building the regression function model, the possibility of predicting the values of the variables was taken into account, i.e. what values the dependent variable will take at different values of the independent variable. The final step in the regression analysis was to use the verified regression model to predict the dependent variable. Making a prediction lets us avoid the consequences of future events, or influence their course. When calculating the prediction, the following were taken into account:

- ex post – when the values of the independent variables are known, the prediction can be compared with the observed values,
- ex ante – when the value of the independent variable is not known.

The above errors depend on the nature and values of the variables in earlier periods. Usually, we do not know how the independent variable will be shaped in the future period T + s. We only know its value in period T. Therefore, the data was determined predictively assuming the certain probability of variable Y. Such a prediction observed in time series is called a conditional prediction.

The development of renewable energy sources depends on a country’s political and economic conditions. Currently, Poland has favourable conditions for the development of RES. The current international situation affects many aspects of energy policy and necessitates a change in the approach to ensuring energy security towards greater diversification and independence. The most important changes in the “Energy Policy of Poland until 2040” include (www.gov.pl/ Poland's energy policy until 2040 [access: 10.12.2023]):

- Increase technological diversification and expand capacity based on domestic sources;
- Further development of renewable energy sources;
- Improving energy efficiency;
- Further diversification of supply and provision of alternatives to hydrocarbons;
- Aligning investment decisions in gas-fired generation capacity with fuel availability;
- Utilisation of coal units;
- Implementation of nuclear power;
- Development of grids and energy storage;
- Negotiating changes to EU regulations.

Results and discussion

The fastest growing sector of the energy industry is wind power. Wind turbines, now often clustered in so-called wind farms, are used to produce wind-based electricity. The amount of energy generated by such power plants is determined not only by the strength of the wind, but also by the frequency of its occurrence in a given area. In Poland, there are favourable conditions for the construction of wind turbines mainly in coastal areas and mountain passes. In Europe, Germany and Spain remain the leaders in the use of this energy source.

Energy from micro wind turbines is stored in batteries and then used to power boats, caravans, road lighting and warning traffic signals (Lowitzsch, Hoicka, Tulder, 2020). Large power plants produce energy that is consumed locally in households, businesses or transmitted directly to the grid. The number of wind farms and their installed capacity is increasing every year. New wind farms continue to be built, and existing installations and turbines are being upgraded. Thanks to these developments, wind energy is becoming an important source of renewable energy for many countries, which, wishing to become independent of fossil fuels, are thus diversifying their energy mix (Chart 5).

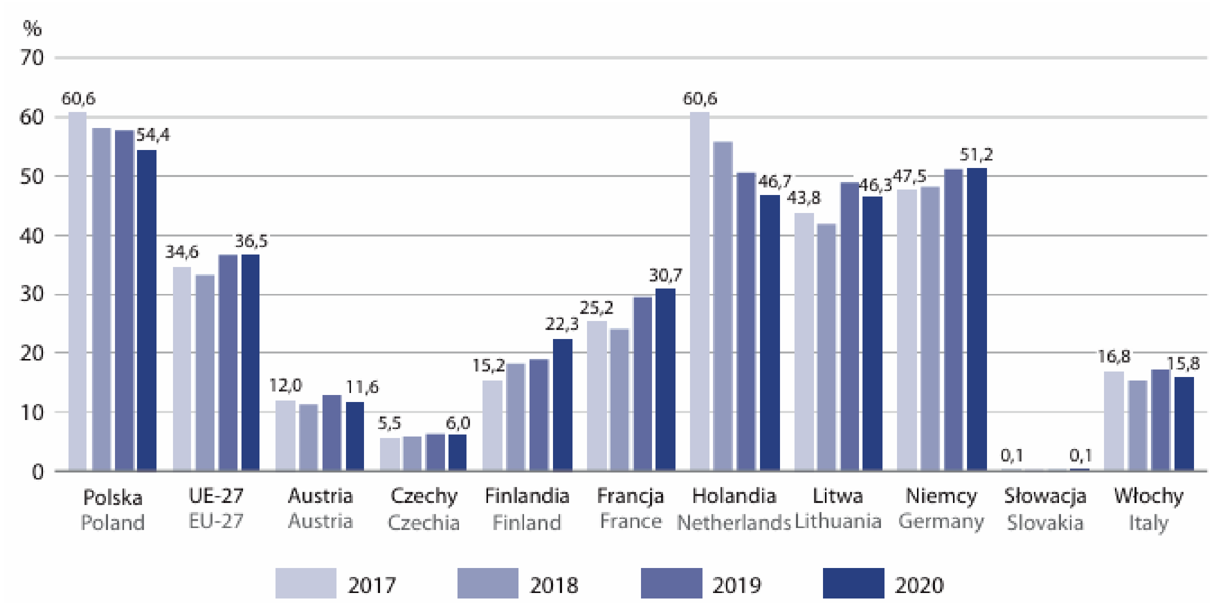

Chart 5. Share of wind energy in the production of electricity from renewable sources in Poland and selected EU–27 member states

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

Table 1 shows the lowest, highest and average wind speeds in Poland. These data are supplemented with annual wind speed values.

Table 1. Extreme values and average wind speeds (in m/s) during the year

Season	MIN	MAX	MEAN
Spring	1.42	11.69	3.32
Sumer	0.89	8.47	2.62
Autumn	1.08	13.18	3.26
Winter	1.27	15.05	3.76
Year*	0.89	15.05	3.24

* wind speed was measured every hour and every day for 365 days.

Source: own study based on the Clean Energy Project, Słupsk 2021.

An average wind power plant needs to be powered with a wind speed of at least 2.5–3 m/s, but the most favorable wind velocity is in the range of 6–8 m/s. Too high a wind speed, i.e. above 25 m/s, is not at all desirable because if the wind blows too strongly, the wind turbine shuts down and sets the blades in a position that offers minimal resistance to the air (Mehrtash, Capitanescu, Heiselberg, Gibon, 2020, p. 6846). Wind conditions for energy purposes in Poland are described as moderate, but high enough to be a potentially efficient source of renewable energy. For the country as a whole, annual average wind speeds range from 2.6 m/s to 3.8 m/s (Chart 6).

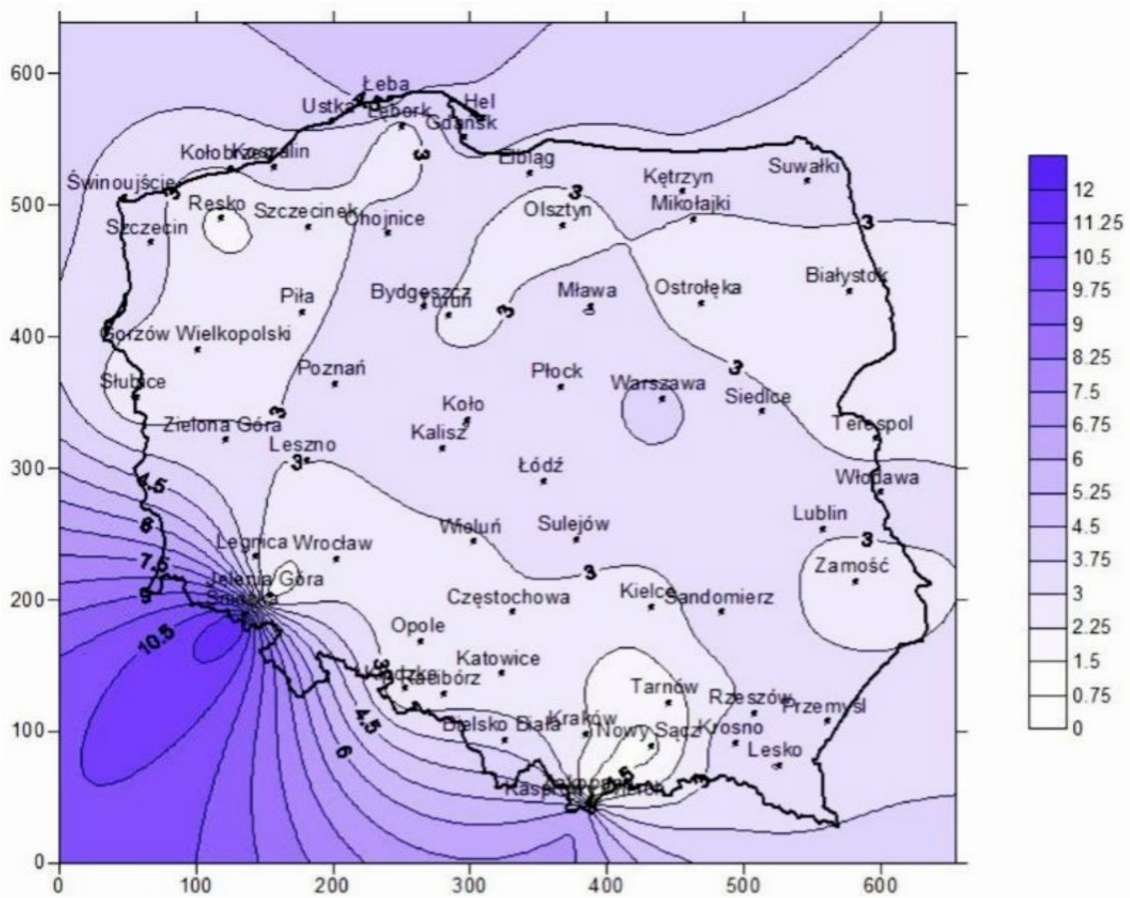

Chart 6. Annual wind map of Poland

Source: Clean Energy Project, Słupsk 2021.

Wind velocity is subject to seasonal variation. In winter, wind speeds are highest, reaching an average of 3.76 m/s (EDPR inaugurates a new Wind Farm in Poland. www. Zasoby energii wiatru na terenie Polski – mapa lokalizacji w których wykorzystamy wiatrak do produkcji energii elektrycznej (remont.biz.pl) [access: 25.04.2023]). The lowest wind speeds are recorded in summer, on average at 2.62 m/s. Wind speeds are much alike in the first and third quarters of the year, but they differ locally, since a characteristic feature of wind energy is its high variability, not only in space, but also in time (http://www.eera-dtoc.eu/wp-content/uploads/files/D7-20-EERADTOC-final-summary-report-web-version.pdf [accessed 10.03.2023]). Being 210 metres high, the world's highest wind turbines have been built in Poland.

The formulation of the wind power production trend (in GWh) over time assumes that the development trend is linear (Table 2). Wind power generation shows an upward development trend in the years under review, but not as strong as photovoltaic power generation.

Table 2. Supporting calculations for determining the parameters of the trend function of wind electricity production (in GWh) in 2013–2021

t	yt_{emp}	yt t	t^2	$\hat{y}t_{teor}$	$(yt-\hat{y}t_{teor})^2$	$(yt-\bar{y}t)^2$
1	6004	6004	1	7508.27	2262,818.21	41443,981.29
2	7676	15,352	4	8741.62	1135,538.89	22711,896.49
3	10,858	32,574	9	9974.97	779,747.86	2508,105.69
4	12,588	50,352	16	11,208.32	1903,526.09	21,403.69
5	14,909	74,545	25	12,441.67	6087,733.76	6087,569.29
6	12,799	76,794	36	13,675.02	767,405.21	127,663.29
7	15,107	105,749	49	14,908.37	39,455.20	7103,824.09
8	15,800	126,400	64	16,141.72	116,770.28	11278,178.89
9	16,234	146,106	81	17,375.07	1302,033.15	14381,539.29
	∑111,975	∑633,876	∑285	–	∑14395,028.65	∑105664,162.01

Source: own study.

Forecasts of electricity production from wind have steadily been increasing in subsequent years and will be at 22,308 GWh in 2025 (Figure 3).

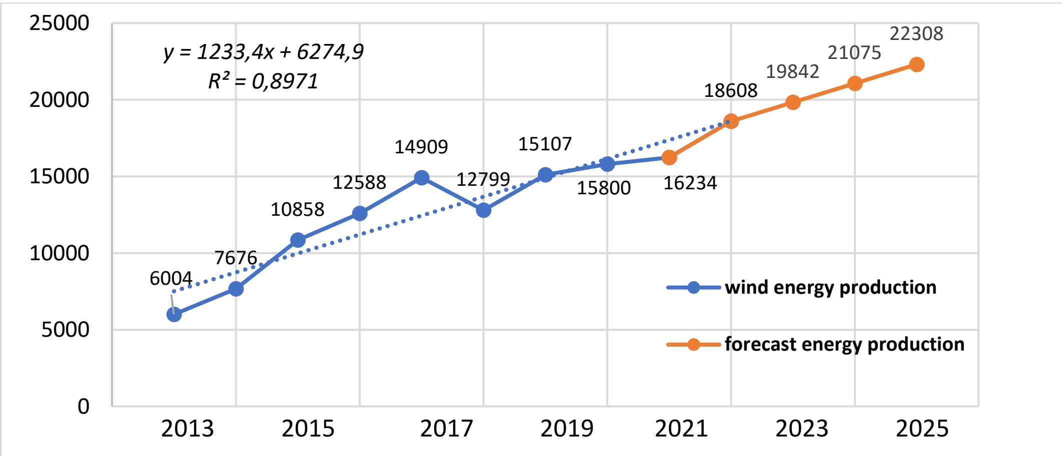

Figure 3. Trend equation of wind power generation in 2013–2021 and projections to 2025 (in GWh)
Source: own work based on data from CSO, Renewable Energy, 2014-2022.

To test the consistency of empirical data with theoretical data, the average error of residuals, the coefficient of convergence, and the coefficient of residual variation were calculated (Ostasiewicz, Rusnak, Siedlecka, 2011). The calculated coefficient of convergence reports that only 10.3% of the energy production information was not explained by the independent variable. In turn, the coefficient of residual variation indicates that the random deviations of the trend equation account for on average 11.5% of the average level (Table 3).

Table 3. Forecasts and forecast errors of wind power production (in GWh) for 2023–2030

Years	2023	2024	2025	2030
Wind power production forecasts	19,842	21,075	22,308	28,475
Average error of residuals	1434			
Coefficient of residual variation in %	11.53			
Coefficient of convergence ϕ^2	0.1029			

Source: own study.

A runs test was used to verify the hypothesis that wind power generation from 2013–2021 followed a linear trend. The null hypothesis was verified: H_o: $f(t) = \alpha_0 + \alpha_1 t$, towards the alternative hypothesis: H_1: $f(t) = \alpha_0 + \alpha_1 t$ (Srivastava, Shetti, Reddy, Nadagouda, Badawi, Bonilla-Petriciolet, Aminabhavi, 2023, p. 117410). The test value of the null hypothesis is a fixed number of runs, k=5. The result obtained was confronted with the critical value of the number of runs. At a confidence level of α=0.05 and a fixed number of elements n_1=4(a) and $n_{2=}$5(b), the critical value was $k_{0.05}$=2. Thus, there is no basis for rejecting the null hypothesis. Thus, there is no basis for rejecting the null hypothesis Ho: $f(t) = \alpha_0 + \alpha_1 t$, as the null hypothesis test value is greater than the critical value read from the tables (5 > 2), confirming the presence of a linear trend.

Conclusions

Energy transition is not only a necessity but also an opportunity for a sustainable and efficient energy future of a country. Renewable energy sources (RES) and nuclear power should start playing more and more important roles in reducing the dependence on coal and fossil fuels. Saving energy and increasing energy efficiency can help in reducing the demand for new energy sources. Cooperation with other EU member states and neighbours in the scope of energy security and energy infrastructure is crucial.

Wind power generation is not only carbon-neutral, but in a climate-friendly way can also be used to produce hydrogen and synthetic fuels such as kerosene and diesel. Energy from the sun and wind power can meet the entire global energy demand several times over. This will be essential for the energy transition.

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