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Development of pro-ecological energy in Poland

Abstract

Poland is in the phase of adjusting its economy to the challenges of the energy and climate transition. The concept of the transition assumes a reduction in energy production from sources emitting greenhouse gases, including CO_2. The energy sector is the main sector included in the concept of the European Green Deal. In the EU, a 30% share of energy produced from RES by 2030 is assumed. For Poland, this means very significant obligations in the process of reducing energy production from high-emission conventional sources. This will mean accelerating the development of production from ecological sources, including wind farms, photovoltaic farms, and the generation of energy from biogas and biomass. It will be necessary to launch energy production from nuclear power.

In view of the above, the article refers to documents shaping Poland's energy policy, namely: *Energy Policy of Poland until 2040* and *National Development Concept 2050*. The aim of the article is to present the development of pro-ecological energy in Poland, its adaptation to the requirements of sustainable development: to present trends in Polish energy in the years 2020–2025, and to present the development trends of energy generation and distribution in Poland until 2040. The following research questions were posed in this study:

1. Which renewable energy sources are used in Poland?
2. Does the implementation of pro-environmental energy policy threaten energy security?
3. How does electricity prosumption contribute to the pro-environmental development of the Polish energy sector?

After conducting the analysis, the answers to these research questions are as follows:

1. In the analysed period 2020–2025, both ecological energy sources based on biomass, biogas, and gravitational systems, as well as solar and wind energy, are utilized. Photovoltaic energy is developing the most dynamically. Other sources have relatively low installed capacity. A decline in production and installed capacity in coal-fired power plants is also observed.
2. During 2020–2025, the fastest growth occurs in photovoltaic installations. These installations are highly dependent on weather conditions, time of day, and season, and they possess very high installed capacity. The nature of their operation causes significant energy surpluses or shortages in the power system within very short periods. This entails substantial risks in maintaining proper energy quality parameters. In extreme cases, it could lead to a blackout, representing a serious threat to Poland's energy security.

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3. Prosumer energy generation in Poland, as a phenomenon, clearly supports the development of pro-environmental energy. However, its implementation faces challenges. Poland is experiencing an uncontrolled increase in the number of PV installations, while other renewable energy sources are developing relatively slowly. The construction of wind farms – which should be regarded as far less weather-dependent than solar installations – has been practically blocked by legislation. Biomass and biogas sources are also not widely adopted, even though they are completely independent of weather conditions.

The article uses the analytical-synthetic method. Available data concerning both the theoretical dimension and the practice of functioning of the energy system in Poland were analysed.

It was found that Polish energy faces many challenges and problems to be solved. The undertaken actions, although costly, are necessary to achieve the goal of living in a pollution-free environment, without the effects of global warming, in a state that eliminates the risk of 'energy poverty.'

Keywords: energy development, RES, prosumption, sustainable development, decarbonisation.

Rozwój proekologicznej energetyki w Polsce

Abstrakt

Polska znajduje się w fazie dostosowywania gospodarki do wyzwań transformacji energetycznej i klimatycznej. Koncepcja transformacji zakłada ograniczenie produkcji energii ze źródeł emitujących gazy cieplarniane, w tym CO_2. Sektor energetyczny jest głównym sektorem znajdującym się w koncepcji Europejskiego Zielonego Ładu. W UE do 2030 r. założono osiągniecie 30-procentowego udziału energii produkowanej z OZE. W sytuacji Polski oznacza to bardzo duże zobowiązania w procesie ograniczania produkcji energii z wysoko emisyjnych źródeł konwencjonalnych. Będzie to oznaczało przyspieszenie rozwoju produkcji ze źródeł ekologicznych, w tym: farm wiatrowych, fotowoltaicznych i wytwarzania energii z biogazu oraz biomasy. Niezbędne będzie uruchomienie produkcji z energii jądrowej.

Wobec powyższego w artykule przywołano dokumenty kształtujące politykę energetyczną Polski, tj.: *Politykę Energetyczną Polski do 2040* i *Koncepcję Rozwoju Kraju 2050*. Celem artykułu jest ukazanie rozwoju proekologicznej energetyki w Polsce, dostosowywanie jej do wymogów zrównoważonego rozwoju: przedstawienie tendencji w energetyce polskiej w latach 2020–2025 oraz prezentacja trendów rozwoju wytwarzania i dystrybucji energii w Polsce do 2040 r. W opracowaniu postawiono następujące pytania badawcze:

1. Które odnawialne źródła energii znajdują zastosowanie w Polsce?
2. Czy wdrażanie proekologicznej polityki nie zagraża bezpieczeństwu energetycznemu?
3. W jaki sposób prosumpcja energii elektrycznej wpisuje się w proekologiczny rozwój energetyczny polskiej?

Po przeprowadzonej analizie odpowiedzi na pytania badawcze są następujące:

1. W badanym okresie 2020–2025 wykorzystywane są zarówno źródła ekologiczne wytwarzające z biomasy, biogazu, grawitacyjne, jak i ze słońca i z wiatru. Najbardziej dynamicznie rozwija się energetyka z fotowoltaiki. Pozostałe źródła mają stosunkowo niewielką moc zainstalowaną. Obserwuje się też spadek produkcji i mocy zainstalowanej w elektrowniach węglowych.
2. W badanym okresie 2020–2025 najbardziej dynamicznie rozwija się wytwarzanie energii w instalacjach fotowoltaicznych. Są one najbardziej zależne od warunków pogodowych, pory dnia i pory roku i mają bardzo dużą moc zainstalowaną. Charakter ich pracy powoduje bardzo dużą nadprodukcję lub niedobór energii w systemie energetycznym w bardzo krótkim czasie. Niesie to ze sobą duże ryzyko nieutrzymania właściwych parametrów jakościowych energii. W skraj-

nym przypadku może prowadzić do blackoutu. Jest to poważne zagrożenie dla bezpieczeństwa energetycznego Polski.

3. Prosumpcja w Polsce jako zjawisko wpisuje się w rozwój proekologicznej energetyki oczywiście pozytywnie. Gorzej z wykonaniem. W Polsce mamy do czynienia z niekontrolowanym przyrostem ilości instalacji PV, pozostałe OZE rozwijają się stosunkowo wolno. Ustawowo niemalże zablokowano budowę farm wiatrowych, które należy traktować jako dużo bardziej niezależne od pogody niż instalacje solarne. Biomasa i biogaz są również mało popularne, a są całkowicie niezależne od pogody.

W artykule posłużono się metodą analityczno-syntetyczną. Przeanalizowano dostępne dane dotyczące zarówno wymiaru teoretycznego, jak i praktyki funkcjonowania systemu energetycznego w Polsce.

Stwierdzono, że przed polską energetyką stoi wiele wyzwań i problemów do rozwiązania. Podejmowane działania, mimo że są kosztowne, są niezbędne dla osiągnięcia celu, jakim jest życie w środowisku wolnym od zanieczyszczeń, bez efektów globalnego ocieplenia, w stanie wykluczającym ryzyko „ubóstwa energetycznego".

Słowa kluczowe: ekologiczne źródła energii, proekologiczny rozwój energetyki, OZE, prosumpcja, dekarbonizacja.

JEL: O33, O36, M21, L7.

Introduction

Poland is in the phase of adjusting its economy to the challenges of the energy and climate transition. The concept of the transition assumes a reduction in energy production from sources emitting greenhouse gases, including CO_2. The energy sector is the main sector included in the concept of the *European Green Deal* (Europejski Zielony Ład, http). Since 2005, Polish energy policy has been shaped by EU energy policy. In the EU, a 30% share of energy produced from RES by 2030 is assumed. For Poland, this means very significant obligations in the process of reducing energy production from high-emission conventional sources. This will mean accelerating the development of production from ecological sources, including wind farms, photovoltaic farms, and the generation of energy from biogas and biomass. This direction can be described as the development of pro-ecological energy. It will be necessary to launch energy production from nuclear power. Until the completion of the process of achieving zero emissions, demand for electricity will be met on the basis of conventional energy sources – lignite and hard coal. Of course, these sources will gradually be phased out. An expansion of the energy system with RES sources is planned, as well as the construction of a nuclear power plant. At the same time, a programme for the development of prosumption on the energy market is developing. This brings significant challenges for the energy distribution system in terms of maintaining proper energy parameters. At present, the professional energy sector is struggling with the problem of excess electricity during periods of high solar radiation,

related to production from photovoltaic installations, or excess energy resulting from production by wind farms.

The issue of making production sources more ecological should therefore be considered in a multidimensional way through the prism of:

a) protection of the environment against greenhouse gas emissions, including CO_2;
b) conservation of natural resources;
c) stability of the energy distribution system (the National Power System, hereinafter referred to as NPS).

This widely known action plan stems from the adopted Polish Energy Policy until 2040 (Polityka Energetyczna Polski do 2040, http) and the National Development Concept 2050 (Koncepcja Rozwoju Kraju 2050, http). These documents are based on the European Green Deal (Europejski Zielony Ład, http).

The aim of the article is to present the development of pro-ecological energy in Poland, its adaptation to the requirements of sustainable development: to present trends in Polish energy in the years 2020–2025, and to present the development trends of energy generation and distribution in Poland until 2040.

The article uses the analytical-synthetic method. Available data concerning both the theoretical dimension and the practice of functioning of the energy system in Poland were analysed.

RESEARCH METHODOLOGY

The article concerns the development of pro-ecological energy production in Poland. It highlights the need to adapt the national energy sector to the requirements of European Union legislation. The directions of change are presented on the basis of documents that define the development path of the Polish energy sector. These include, above all, the Energy Policy of Poland until 2040 (Polityka Energetyczna Polski do 2040, http) and the National Development Concept 2050 (Koncepcja Rozwoju Kraju 2050, http).

The structure of the paper includes:

1. Research methodology.
2. The need for development of pro-ecological energy.
3. Ecological energy sources in Poland.
4. Energy policy vs. energy security of Poland.
5. Prosumer energy.
6. Legal conditions for the development of Polish energy industry.
7. Energy transformation in Poland in 2020–2025 – identification of challenges and risks.
8. Conclusions.

The article presents Poland's energy policy in the context of the challenges posed by the European Union and analyses data illustrating the actual condition of the Polish energy sector in the years 2020–2025. The data come from the Energy Market Agency. This timeframe is justified by the fact that the most significant development of photovoltaic installations has been observed since 2020. The data concern the installed capacity in individual energy sources and its changes over the examined period, as well as the amount of energy fed into the grid by prosumers (surplus production exceeding their own needs).

The data show:

1. Electricity production in the winter and summer seasons in the years 2020–2025 by energy source.
2. The installed electrical capacity in particular energy sources used in Poland. The data indicate a trend of increasing production from RES and decreasing production from conventional sources.
3. The growth of prosumer activity in 2020–2025, broken down by generation source. Prosumer activity is determined by installed capacity. The highest share of installed capacity is recorded for photovoltaics, while other sources have marginal shares.
4. The increase in the volume of energy fed into the grid by prosumers in 2020–2025. A very high surplus production exceeding prosumers' own needs has been identified.

The article demonstrates that there is a systematic decline in energy production from hard coal and lignite; the share of production from natural gas, biogas, biomass, and wind power plants is increasing. However, the most significant impact on the stability (security) of the energy system comes from the rapid growth of photovoltaic production. Accordingly, the changes in installed capacity for individual energy sources are presented. A significant disproportion in photovoltaic production relative to other RES sources used by prosumers is also shown.

The analysis includes data for January, representing the winter period, and June, representing the summer period. There is therefore no need to present data for other months, as the trends and values remain similar.

The article poses the following research questions:

1. Which renewable energy sources are used in Poland?
2. Does the implementation of pro-ecological energy policy threaten energy security?
3. How does electricity prosumption fit into Poland's pro-ecological energy development?

In the context of these research questions, there is also a need to identify risks associated with the use of ecological energy sources.

The need for development of Pro-ecological energy

There are many indications that we are dealing with an anthropogenic climate change. The burning of fossil fuels – coal, natural gas, and crude oil – for the purpose of generating electricity contributes to the release of greenhouse gases into the atmosphere, resulting in the so-called greenhouse effect. Climate warming should be considered not only in terms of the increase in average air temperature, but also the frequency and structure of precipitation, storms, droughts, and other consequences having a negative impact on the natural environment.

Excessive production of greenhouse gases began to intensify with the era of the industrial society, already in the 18th century. The intensification of this process, however, took place in the 20th century. In socio-economic development, in the existing model of socio-economic development, humanity maximised the importance of the economy, including the size of the Gross Domestic Product,[2] disregarding its negative impact on the environment. Most streams of economics treated the natural environment in a superficial way. For example, W. Petty in the 17th century already took into account two factors of economic development – labour and land; A. Smith – labour, land, and capital. He treated natural resources as a barrier to economic development. Another economist, T. Malthus, emphasised the limitation of natural resources. A. Marshall (19th/20th century), on the other hand, drawing attention to the scarcity of natural resources, created the concept of external effects – external costs and benefits (Czuma, Jarosz, 1998, pp. 43, 50, 79). Within this concept – global external costs – contemporary climate changes are now included.

Until quite recently, the model of socio-economic development was highly intensive in terms of natural resources. The basis of state development was non-renewable fossil resources: crude oil, lignite and hard coal, and natural gas, causing excessive emission of greenhouse gases. In the existing model, it was assumed that the degradation of the natural environment was a normal phenomenon in the initial phase of socio-economic development. After reaching the turning point, that is, a high level of income, the second phase of development was to bring an improvement of the natural environment.

The economic crisis in the mid-20th century, having causes in the environment, contributed to the interest of social sciences, including economics, in the issues of the natural environment. The first mention of the depletion of the Earth's energy resources appeared in the First Report to the Club of Rome – The Limits to Growth. Environmental economics emerged, followed by ecological economics, which criticised the former. The greatest achievement of ecological economics is the paradigm of socio-economic development, referred to as sustainable development.

[2] Based on: 2022-ZMKL-02-Tekst 13..29 (https://publikacje.pan.pl/Content/126593/PDF/2022-ZMKL-03.pdf).

It was formulated in 1987 in the Report of the United Nations World Commission on Environment and Development – Our Common Future. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is associated with the integration of political, economic, and social activities while maintaining natural balance. The definition of sustainable development was given by the World Commission on Environment and Development. Sustainable development is "that which meets the needs of the present without jeopardising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 11).

ECOLOGICAL ENERGY SOURCES IN POLAND

The impact of climate on the energy transition should be considered through the prism of the technology used for energy generation. It can be divided into 3 methods of energy production (Zacharski, Chędożko, 2021, p. 275):
– conventional energy,
– energy based on RES,
– nuclear energy.

The conventional sources with the largest share in electricity production include coal-fired power plants fueled by hard coal and lignite, as well as gas-fired power plants. The disadvantage of these power plants is their reliance on fossil fuels. In the case of wind power plants, a significant problem is the high emission of greenhouse gases. Renewable energy generation is based mainly on wind farms and photovoltaic installations; their major drawback is the strong dependence on weather conditions and seasonal variation, which is particularly evident in photovoltaics. Other renewable power plants include biogas and biomass facilities (Mohammad, Bolton, Wong, Pandey, 2019). Their advantage lies in independence from weather conditions and the ability to utilize waste. Nuclear power plants are perceived as stable and safe. In the Polish context, they are expected to replace coal-fired power plants (Jelley, 2022).

Poland is largely dependent on conventional energy sources. An increasing share of RES in the energy mix is observed, but production is dominated by sources highly dependent on weather conditions. Nuclear energy, considered ecological, is unfortunately still in the preparatory phase for construction. The development of RES production independent of weather influence is, however, costly and currently marginal both in terms of installed capacity and its share in total production.

The development of energy in Poland is based on 3 pillars (Jabłoński, 2023, pp. 17–18):
1. Security of the energy system, related to the continuity of energy supply and optimal system operation.

2. Economic operation of the system, related to the acceptance of energy prices by its users.
3. Sustainable development of the natural environment.

The task of the pro-ecological development of the energy system in Poland is to combine the indicated priorities in practice. However, at this stage, the implementation of points 1 and 2 is at risk. For point 1, due to the dynamic development of energy sources dependent on weather conditions, which in extreme cases can negatively affect the stability of the NPS. For point 2, due to negative energy prices in the event of excess energy in the grid.

Currently, electricity constitutes one of the fundamental factors in the functioning of societies. A continuous increase in demand is observed along with socio-economic and technological development. The 20th century is the period in which the demand for energy particularly increased. This trend continues into the 21st century. Data from the International Energy Agency clearly show an increasing demand for electricity. Thus, given the necessity to implement ecological policies, the need to use renewable energy sources grows.

The direction of the energy transition is determined by:

a) the process of implementing the European electricity market;
b) the process of changing the structure of sources generating electricity, and
   1. actions of the European Commission aimed at the efficient and safe functioning of interconnected power systems in Europe, systems based on generation sources using clean technologies and supporting the decarbonisation of the European economy (Myślecki, 2018).

In the context of EU goals, the Ministry of Economy document "Energy Policy of Poland until 2040" assumes that part of the demand for electricity will be met by renewable energy sources, which are sources using wind, solar, marine (wave) energy, biomass, gas, geothermal energy, and biogas in the conversion process (Sobierajski, 2017, p. 11). The European Commission has also published two Action Plans regarding the challenges facing the EU in relation to long-term reductions in greenhouse gas (GHG) emissions. These plans, in a perspective up to 2050, assume a reduction of GHG emissions to nearly 0. Therefore, an energy policy focused on decarbonisation becomes necessary (Sobik, 2023, p. 12) and intensification of the use of ecological energy sources.

ENERGY POLICY VS. ENERGY SECURITY OF POLAND

The aim of energy management in Poland is to ensure the continuity of energy supply and to minimise energy costs on a national scale. Energy policy constitutes a part of the state's economic policy. Its main tasks are:

a) energy security;

b) protection of the natural environment;
c) sustainable development;
d) development of modern technology;
e) reduction of energy consumption.

Energy policy should integrate the implementation of security and development (Sobik, 2023, pp. 34–35). Policy is a set of coherent, precise, and legally compliant regulations, rules, and procedures through which the state influences energy management: acquisition, processing, management, and access to energy resources. The objective of energy policy is to ensure energy security (Sobik, 2023, pp. 35–26). Energy security, in turn, encompasses:
– energy,
– economic growth, and
– political authority.

New problems and challenges facing the energy sector contribute to considering energy security not only in geopolitical terms but also from the perspective of ensuring oil supply. Currently, energy security is approached in terms of a global strategy, taking into account challenges and threats both from the past and those that may arise in the future. A strategy constitutes a supreme, long-term plan concerning primarily energy enterprises (Gryz, Podraza, Ruszel, 2018, pp. 49–63).

In connection with the above, Polish energy faces the challenge of adapting to EU requirements. The main problems are (Szczerbowski, 2013, p. 207):
a) technological adaptation of electricity generation and heating systems with regard to emission levels;
b) dependence of electricity generation and heating on coal;
c) poor technical condition of energy generation and heating sources and networks;
d) limited use of RES;
e) lack of nuclear energy;
f) low energy efficiency in the use of energy, generation sources, and electricity networks.

Therefore, in the context of Poland's situation, three scenarios for building Poland's energy security can be indicated:
a) basing energy security on hard coal and lignite;
b) subordinating the energy sources used to overarching criteria related to the protection of the natural environment;
c) treating all energy sources equally (Bożyk, 2013, p. 32).

Taking into account EU energy and ecological policy, as well as the "Development Strategy for Poland until 2025" and "Energy Policy of Poland until 2040," the implementation of the second scenario is determined.

In the context of implementing the second development scenario, ecological energy sources can be divided into two categories:

1. Independent of the season and weather conditions – sources generating energy from biogas, biomass, and gravitational systems.
2. Dependent on the season and weather conditions – sources generating energy from wind and solar power, such as wind farms and photovoltaic installations.

The first category has a positive impact on the stability (security) of the energy system, as these sources are predictable and easy to control. The second category, however, poses a threat to the stability (security) of the energy system due to the unpredictability of weather conditions. This results from sudden increases and decreases in production within short time intervals (power deficits and surpluses in the system) (Marszałek, 2018).

PROSUMER ENERGY

Due to the increasing energy needs of the state and the necessity of ensuring energy security, Poland continues to seek innovative solutions in the energy sector. One of the concepts that has gained very substantial financial and legislative support in recent years is prosumer energy, in which the client is both producer and consumer. There is a transition from being an energy consumer to being an energy prosumer (Bożyk, 2013, p. 155). Three segments of prosumer energy can be distinguished (Całus, Flasza, Szczepański, Michalski, Luft, 2016, p. 124):

a) homeowners, farms, housing communities;
b) local governments, cooperatives;
c) entrepreneurs, railway infrastructure (PKP).

The development of the prosumer model is currently preferred by the European Commission (Godlewska-Majkowska, Wachowiak, Strojny, Majewski, 2020, p. 143).

Unfortunately, the construction of prosumer installations based on energy sources highly dependent on weather on the scale seen in Poland poses a threat to the stability of the NPS. Poland's situation, for example German where the prosumer model works well, differs due to the lack of nuclear or other ecological energy independent of weather conditions. The regulation of production in a nuclear power plant is fluid and very easy. When weather conditions allow high RES production, nuclear output is reduced. In Poland, this is not so easy due to the characteristics of coal-fired power plants, which are difficult to regulate. Therefore, the rapid implementation of a nuclear power plant programme in Poland should be pursued. The second direction for building energy stability is energy storage (Rifkin, 2012). Of course, due to technological limitations, the construction of galvanic storage is not feasible here. The focus should be on gravity-based storage and, above all, on using surplus produced energy to generate the most environmentally friendly fuel, hydrogen.

The European electricity market stabilizes the situation in transmission networks. National Power Systems are interconnected, and in the event of excess energy in Poland's system, energy can be transmitted to neighboring country, which purchases it at an attractive price and simultaneously reduces its nuclear production. Of course, this mechanism also works in the opposite direction, i.e., in the event of an energy shortage in the system, energy can be acquired from abroad (Koszarek-Cyra, 2017).

Prosumer energy generation has both advantages and disadvantages. Its main advantage is its positive impact on the environment. In addition, it provides financial savings for prosumers who consume the energy they generate or have the possibility to "store" the surplus energy in the power grid. However, an excessive number of prosumer installations feeding surplus production into the grid becomes a disadvantage, as it significantly reduces the profitability of prosumer systems (negative electricity prices). From the perspective of the professional energy sector, excessive surplus production from weather-dependent energy sources destabilises the power system.

Legal conditions for the development of the Polish energy industry

The process of Poland's energy transformation is governed by a series of acts and regulations. These are supplemented and amended as needed. They are executive and regulatory documents. Long-term assumptions, however, have been set out in two main documents: *Energy Policy of Poland until 2040* and *National Development Concept 2050.*

The document entitled *National Development Concept 2050* assumes "the development of ecological energy sources, energy storage, nuclear energy, and the production and utilisation of hydrogen." The document recommends the introduction of a series of "legislative solutions as well as investments in the generation, storage, and utilisation of alternative energy sources" (Koncepcja Rozwoju Kraju 2050, http). The aim of the document is to outline a direction allowing for increased energy efficiency and achieving a "state close to zero emissions" by 2050. In recent years, Poland has made extensive use of ecological solutions for generation of electricity. Solutions allowing electricity generation from the sun, wind, and biomass (biogas) have been widely introduced in Poland. "The pursuit of ensuring energy security has resulted in legislative and investment solutions that support the generation, storage, and utilisation of energy from alternative sources, such as RES" (Koncepcja Rozwoju Kraju 2050, http). Recently, the development of so-called citizen energy has also been observed. "A particular role will be played by the creation of local structures, focusing on cooperation and the mutual satisfaction of energy needs, e.g., energy cooperatives

or other forms of social economy" (Koncepcja Rozwoju Kraju 2050, http). These assumptions align with the concept of prosumer energy, which aims to generate energy for personal needs and feed surpluses into the NPS. However, the assumptions of the National Development Concept 2050 go further towards maintaining a stable level of energy production. Within the scope of the National Development Concept 2050 and Energy Policy of Poland until 2040, "possible directions of energy transformation are considered, focusing on the opportunities and risks associated with the proposed solutions to the coal gap problem. (…) The coal gap will vary over time, depending on the decommissioning of successive coal units, so it is better to act preventively and faster than international/EU obligations require" (Raport Transformacja Energetyczna w Polsce, http).

The document *Energy Policy of Poland until 2040* (PEP2040) "defines the framework for the energy transformation in Poland. It contains strategic assumptions regarding the selection of technologies serving the construction of a low-emission energy system. PEP2040 contributes to the implementation of the Paris Agreement, concluded in December 2015 during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), taking into account the need to carry out the transformation in a just and equitable manner. (…) The policy considers the scale of challenges related to adapting the national economy to EU regulatory conditions associated with the climate and energy targets for 2030, the European Green Deal, the economic recovery plan after the COVID pandemic, and the pursuit of climate neutrality according to national capabilities, as a contribution to the implementation of the Paris Agreement" (Polityka Energetyczna Polski do 2040, http). Of course, such ambitious goals carry risks for the NPS in terms of maintaining proper electricity parameters. Currently, in addition to the risk of electricity shortages or surpluses in the system, attention must be paid to the geopolitical situation and potential shortages of non-renewable resources. It is necessary to fully agree with the conclusion drawn in the PETiREE study stating that "One of the most important challenges faced by the Polish economy and administration in 2024 was ensuring and maintaining the country's energy security under variable geopolitical conditions. Therefore, the harmonious cooperation of all entities involved in the energy transformation is essential to achieving the EU goal of climate neutrality by 2050" (Energetyka, Dystrybucja, Przesył PTPiREE 35 lat, http). It is important to emphasise the risk associated with the stability of the NPS in the context of the rapid development of energy from relatively cheap sources dependent on weather conditions.

It is worth emphasising the limited use of sources based on ecological products, such as biogas and biomass, as well as the low growth dynamics in energy production from gravity-based sources (hydropower plants). Concern is also raised by the distant perspective of building nuclear energy.

Energy Transformation in Poland in 2020–2025 – Identification of Challenges and Risks

After outlining the directions of development recorded in the documents *Energy Policy of Poland until 2040* and *National Development Concept 2050*, to fully illustrate the situation in which Poland finds itself in 2025 and the chances of achieving the assumptions, it is necessary to examine the actual state. For this purpose, publicly available reports from the Energy Market Agency for the years 2020–2025 can be used. The main parameters illustrating the situation and development trends are: the value of energy production, installed capacity, the increase in installed capacity by prosumers, and the value of capacity introduced into the grid by prosumers.

The analysis was conducted with a division by energy generation sources. The analysis of energy production volumes was based on the production values from renewable and non-renewable energy sources in summer and winter periods. Data are provided for January, which is representative of the winter period, and for June, which is representative of the summer period. There is no need to show other months as the trends and values are similar.

The data refer to January, which is representative of the winter period, and June, which is representative of the summer period. There is no need to present data for the remaining months, as the trends and values are similar.

Energy production in the winter period is illustrated in Figure 1.

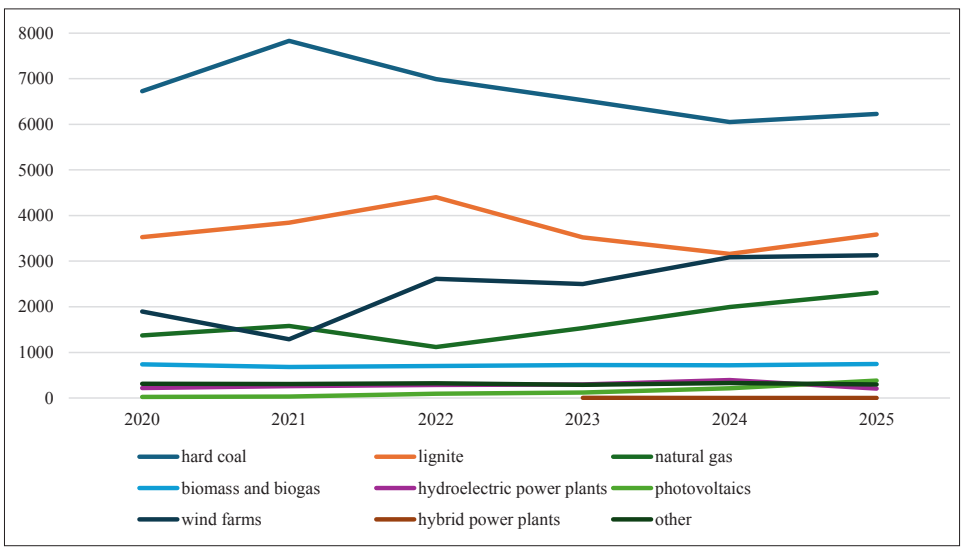

Figure 1. Electricity production in the winter period [GWh] (January)

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

Energy production in the summer period is illustrated in Figure 2.

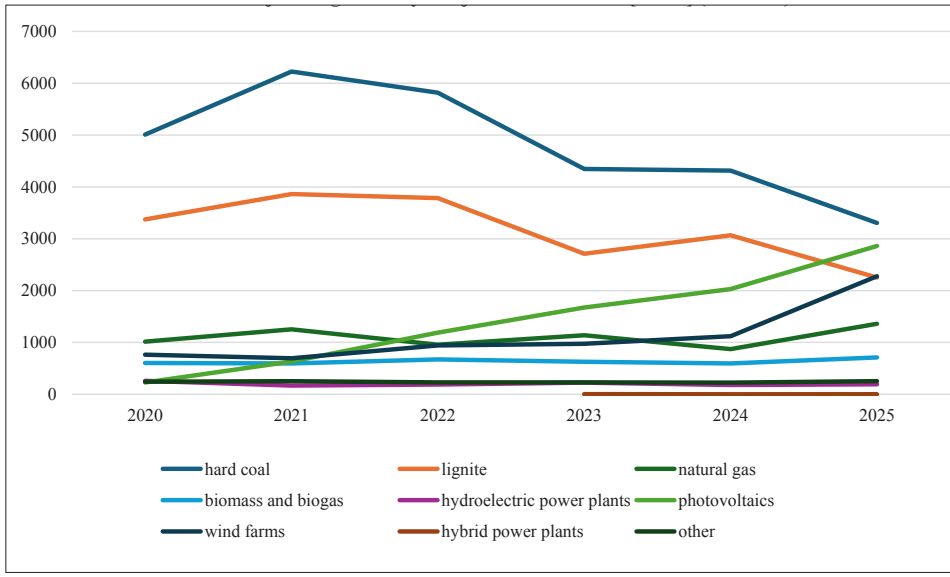

Figure 2. Electricity production in the summer period [GWh] (June)

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

Analysing the trends in the graphs for both winter and summer periods, a decline in energy production from hard coal is visible from 2021. In the case of lignite, the decline begins in 2022.

It was also noted that from 2022 there has been a systematic increase in energy production from natural gas, which, although not classified as a renewable fuel, is recognised as an ecological source. In the case of this source, it should also be noted that it is independent of weather conditions and easily adjustable. Production from biogas and biomass, as well as from hydroelectric power plants and sources classified as "other," remains at a constant level without a clear upward trend. These sources are classified as Renewable Energy Sources. At the same time, they are easy to regulate and independent of weather conditions.

During the period under study, a high growth dynamic in production from wind power plants is also evident. This trend is visible in the winter period. Particular attention is drawn to the very high growth dynamics in the summer period from photovoltaic installations. These sources are dependent on weather conditions and, in extreme cases, may cause an energy surplus in the NPS. From 2023, a new category of sources defined as hybrid appears. These should be understood as consisting of more than one generation, with the generations based on different energy sources, e.g., solar and wind, or biogas and biomass, or all three.

Analysing the installed capacity of energy sources, illustrated in Figure 3, a clear trend can be seen towards the development of relatively inexpensive sources generating energy from the sun.

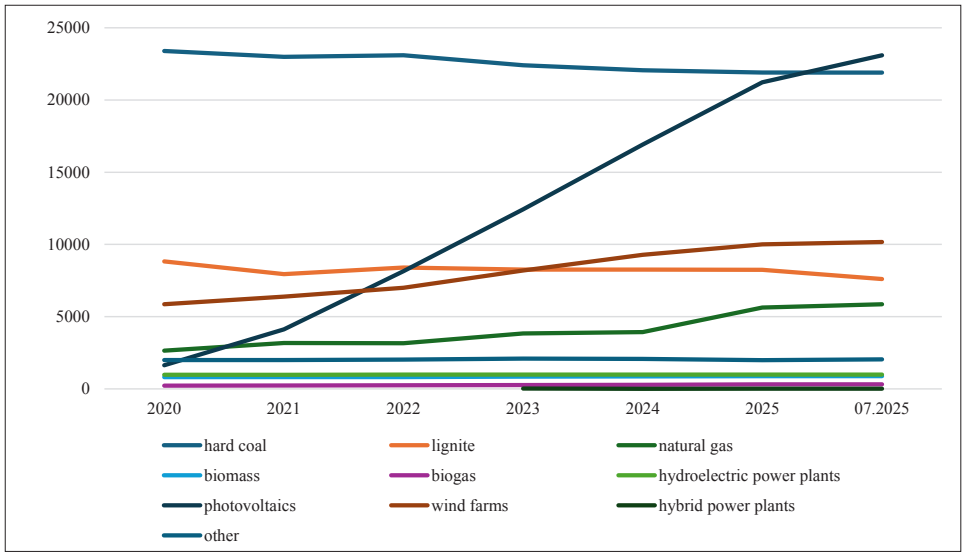

Figure 3. Installed electric capacity [MW]

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

In 2025, the installed capacity of photovoltaics exceeded the installed capacity of coal-fired power plants and is currently dominant. A steady upward trend is also visible in the installed capacity of wind power plants and power plants generating energy from natural gas.

Other renewable energy sources (RES) are not developing as dynamically. Unfortunately, this constitutes a significant risk factor for maintaining the stability of the NPS due to the strong dependence of energy generation sources on weather conditions. However, the dominant RES source is photovoltaic installations due to their relatively low cost. The reason for this phenomenon is the enormous development of prosumer installations. The scale of the phenomenon is evidenced by the installed capacity of photovoltaic installations and the huge disparity in comparison with other RES generation sources. The data are shown in Table 1.

Table 1. Prosumer energy installed capacity [MW]

	01/2022	01/2023	01/2024	01/2025	07/2025
1	*2*	*3*	*4*	*5*	*6*
Hydro	1.23	1.04	1.04	0.73	0.72
Wind	0.68	0.32	0.37	0.44	0.55

1	*2*	*3*	*4*	*5*	*6*
Photovoltaic	6,113.27	9,019.21	10,749.22	12,101.56	12,661.96
Hybrid	0.6	1.04	0.15	0.32	1.01
Biogas	0.53	0.8	0.88	1.07	1.2
Biomass	0.14	0.36	0.41	0.03	0.03
Other			1.21	1.59	2.23

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

The table illustrates the scale of the disparity.

This disparity is also visible when analysing the energy fed into the grid. The data are illustrated in Figure 4.

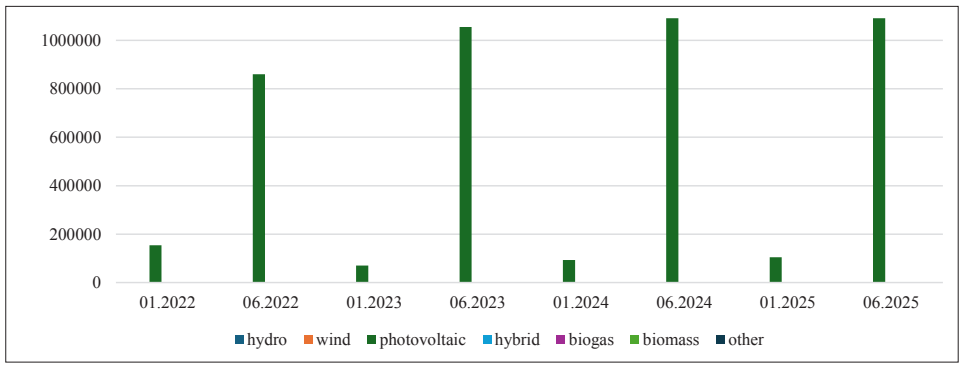

Figure 4. Prosumers – Energy fed into the grid [MW]

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

To show the scale of disproportions, these data are reproduced in Table 2 because they are marginally small and not visible on the graph Figure 3. To illustrate the scale of the disproportions, these data are presented in Table 2, as they are very small and therefore not visible on the graph shown in Figure 3.

Table 2. Prosumers – Energy fed into the grid [MW]

	01.2022	06.2022	01.2023	06.2023	01.2024	06.2024	01.2025	06.2025
Hydro	162,5	138,8	165,1	146,8	148,9	152,1	135,5	100,5
Wind	6,2	22,3	2,6	30,1	17,2	30,3	4,6	25,6
Photovoltaic	153938,2	860407,1	69810,8	1055222	92636,5	1091750	104187,7	1091434
Hybrid	14,2	55,4	7,2	102,6	0,8	2,5	0,9	47,1
Biogas	43,6	65	93,8	113,2	115,2	119,3	147,1	162
Biomass	4,8	25	2,9	37,9	2,2	41	0	0
Other					22,8	98,9	12,9	226,9

Source: own elaboration based on (Agencja Rynku Energii / Energy Market Agency, http).

In this case, concern arises from the strong dependence of production on weather conditions and the season. With such a high installed capacity in photovoltaic installations, it is evident that prosumers feeding surplus energy into the grid during the summer period generate a risk of NPS destabilisation. The graph also shows the scale of solar prosumption compared to other renewable energy sources.

Conclusions

One of the fundamental economic objectives facing Poland is energy transformation. The most important actions fall within the framework of decarbonisation, including the development of RES and the increase of energy security. The measures taken by Poland have a long-term scope. The goals set for the Polish energy sector have been specified, among others, in the following documents: *Energy Policy of Poland until 2040* and *National Development Concept 2050.* The outlined direction is consistent with the concept of sustainable development. Considering the need to reduce greenhouse gas emissions, the broadly understood assumptions of ecological policy, and the limited availability of natural resources, this is the only proper direction. In recent years, there has been a dynamic development of ecological renewable energy sources in Poland. A decline in production from coal-based sources is also observed. This is a path towards achieving the country's decarbonisation. After conducting the analysis, the answers to the research questions are as follows:

1. In the analysed period 2020–2025, both ecological energy sources based on biomass, biogas, and gravitational systems, as well as solar and wind energy, are used. The fastest-growing sector is photovoltaic energy. Other sources have relatively low installed capacity. A decline in production and installed capacity in coal-fired power plants is also observed.
2. In the analysed period 2020–2025, the most dynamic growth is recorded in photovoltaic installations. These are the most dependent on weather conditions, time of day, and season of the year, and they also have very high installed capacity. The nature of their operation causes significant surpluses or shortages of energy in the power system within very short time intervals. This entails substantial risks in maintaining proper energy quality parameters. In extreme cases, it may lead to a blackout. This constitutes a serious threat to Poland's energy security.
3. Prosumer energy generation in Poland, as a phenomenon, clearly fits into the development of pro-environmental energy production. The problem lies in its implementation. Poland is experiencing an uncontrolled increase in the number of PV installations, while other RES sources are developing relatively slowly. The construction of wind farms – which should be treated as far less

weather-dependent than solar installations – has been practically blocked by legislation. Biomass and biogas sources are also not widely used, even though they are completely independent of weather conditions.

The following threats should also be noted:

a) excessive growth dynamics of energy from sources dependent on the season and weather conditions, particularly photovoltaic installations;
b) lack of easily regulatable energy sources that could quickly respond to surplus or deficit in the NPS, e.g., nuclear power plants;
c) legislative barriers to the development of wind energy, which should be treated as more stable than photovoltaic installations;
d) low share of hybrid RES solutions;
e) lack of developed energy storage technology;
f) too slow development of hydrogen-based energy;
g) high energy prices,
h) economic risks for producers and prosumers resulting from the Energy Market (negative energy prices).Of course, issues such as negative electricity prices and non-market production limitations are only briefly mentioned in this study, as these topics are very extensive and deserve a separate analysis;
i) low share of biomass and biogas power plants in production due to high construction costs.

Thus, the Polish energy sector faces many challenges and problems to resolve. The undertaken actions, although costly, are necessary to achieve the goal of living in a pollution-free environment, without the effects of global warming, in a state that eliminates the risk of 'energy poverty.'

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