Mapping Renewable Energy Sources potential, challenges, and opportunities in Poland

RENEWSTART

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INTRODUCTION

Noticeable climate changes, such as rising temperatures, increasingly severe weather events, hydrological droughts, and ongoing environmental degradation and energy crises, encourage actions aimed at mitigating the threats caused by economies' dependence on imported non-renewable energy resources. The European Union has set ambitious goals to minimize the impacts of human activity. Additionally, the unstable situation in Eastern Europe prompts and mobilizes European countries to invest in clean technologies and renewable sources. European Green Deal[1] As a strategic document, it aims to give the European economy an advantage and ensure energy independence, thereby contributing to a transition away from non-renewable energy sources and achieving climate neutrality. The European directive on renewable energy, which came into effect in November 2023, stipulates the use of renewable energy sources (RES) to reach 42.5% by 2030 (in accordance with RED III) in the EU's energy consumption. However, European countries are expected to strive for a 45% share of RES. This follows the report "Understanding Renewable Energy Goals" authored by the Energy Forum [2] this means that for Poland, the share of renewable energy sources (RES) is at 31.5% of the entire economy. It is estimated that Poland's potential is much greater. However, in order to achieve goals that are more ambitious than those defined by the European Union, changes to our internal conditions are necessary.

European directives, and thus the ambitious goals set by the European Union, have become an impetus for Poland to introduce changes in the existing regulations. One such change, implemented in 2023, was the liberalization of the 10H rule concerning the distance of wind turbines from buildings. Currently, the minimum distance from buildings is 700 meters. The intensive development of photovoltaic power plants has been observed since 2018, thanks to the introduction of the government program "My Electricity"[3].

The rapid development of renewable energy sources is primarily driven by the increase in prosumer photovoltaic installations, fueled by government support programs. In 2023, renewable energy accounted for 27% of electricity generation, which is a record result. The growth in the share of energy from renewable sources is also due to the expansion of installed capacity in onshore wind energy, which had been blocked for many years by the previously mentioned so-called 10H rule[4], preventing the implementation of about 99% of planned investments.

Poland should be able to achieve the set targets in RED III[5] related to a 31.5% share of renewable energy sources (RES) without major problems. However, coordination among all sectors of the economy will be crucial. The dynamic development and thus the increase in the share of RES in the energy mix will enhance energy security and reduce costs associated with the import of fossil fuels, which will, in turn, contribute to reducing emissions from the combustion of non-renewable energy carriers. The green transformation based on renewable energy sources also presents an opportunity for the development of the Polish economy.

[1] The European Green Deal - European Commission (europa.eu)
[2] Tobiasz Adamczewski, Jędrzej Wójcik, Zrozumieć cele OZE, Forum Energii, 2023
[3] Mój Prąd (mojprad.gov.pl)
[4] Amendment to the so-called 10H Act adopted by the Government - Ministry of Climate and Environment - Gov.pl Portal (www.gov.pl)
[5] Renewable Energy Directive (europa.eu)

TYPES AND IMPORTANCE OF RENEWABLE ENERGY SOURCES

Changes in the Polish energy system have been observed for several years. Last year brought a record share of renewable energy sources (RES) in the Polish energy mix. In 2023, RES accounted for 27% of energy generation. An unfavorable fact is the increase in energy production based on natural gas by as much as 41%. This is due to a decrease in gas prices and greater flexibility in generating energy needed to complement unstable and weather-dependent RES. Undoubtedly, a positive aspect is the fact that coal consumption has decreased by 33% since Poland became a member of the European Union. Over the years, a steady increase in energy and fuel consumption has been observed, especially those used in transportation. The increase in the share of RES contributes to the observed decrease in greenhouse gas emissions. Since 2005, emissions have increased by 3.2% compared to previous years. The growth of renewable energy sources has led to a 21% reduction in CO_2 emissions compared to 2015[6].

A concerning observation is that if current trends continue, Poland will generate higher emissions than France in the coming years, despite France having an economy four times larger than Poland's. The observed rapid increase in the share of renewable energy sources (RES) is largely due to photovoltaic installations by prosumers. By the end of 2023, the installed capacity in RES reached 28.6 GW, representing an increase of 24.5%. The achievable capacity in 2023 in Poland shows a noticeable increase of 5.6 GW compared to the previous year, totaling 65.2 GW.

The year 2023 was characterized by a 60.5% share of coal in electricity production, which was a nearly 10% decrease compared to 2022. In contrast, the increase in energy production from renewable sources amounted to 27.1%. The production and consumption of electricity over the past few years have remained relatively stable. The noticeable drop in energy consumption was caused by the Covid-19 pandemic. However, this decline was only temporary, as economic growth following the pandemic contributed to a return to levels seen between 2015 and 2018. Despite a significant increase in energy efficiency responsible for reducing demand, it is estimated that energy demand will increase significantly by 2040. Factors contributing to the increased demand will include the electrification of heating, transport, and industry.

The Polish energy system faces many challenges related to the transition away from fossil fuels and the increasing share of unstable energy sources, such as photovoltaic systems and wind energy. Increasing the share of PV installations and developing wind energy installations will require the development of energy storage systems and investments in cross-border connections to enhance the flexibility of the Polish system and its ability to balance supply and demand.

Another challenge that the Polish energy system will have to face is the replacement of natural gas, which currently serves as a transitional fuel. By 2027, this carrier is set to be included in emissions trading rights, which will result in additional costs for users of gas installations. The Polish energy system stands at the threshold of many challenges; however, there are noticeable trends of increasing the share of renewable energy sources in the Polish power system. The chart below illustrates the contribution of individual energy carriers in electricity production.

[6]https://www.adlittle.com/sites/default/files/202404/Rynek%20energii%20w%20Polsce%202024_Arthur%20D.%20Little.pdf

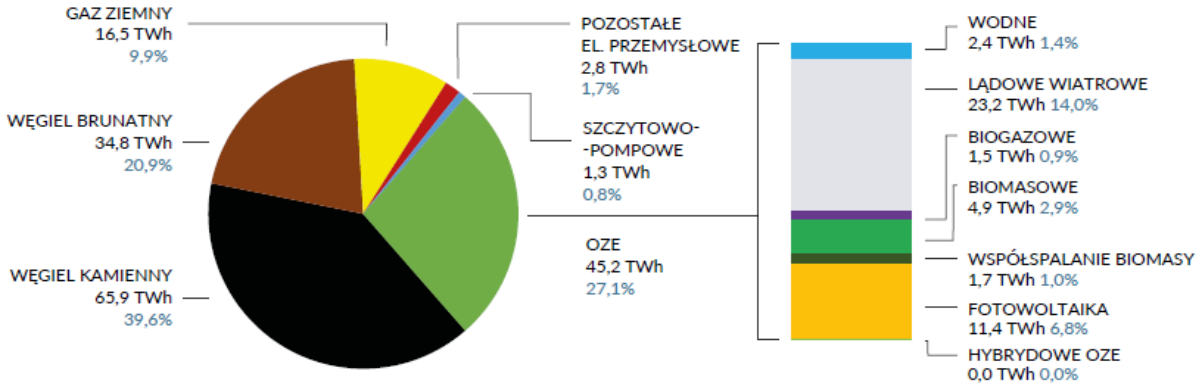

Figure1. Share of individual carriers in electricity production in Poland. Source: Energy Forum 'Energy transformation in Poland'.

- *Solar power industry*

In 2023, photovoltaics was the main technology responsible for the growth of the RES market in Poland. It accounts for 60% of the installed capacity in RES. According to the Energy Regulatory Office[7]the installed PV capacity amounted to 17 GW - at the end of 2023. This represents an increase of 38% compared to 2022. The prosumer segment continues to be responsible for the recorded growth. As of 2019, it is responsible for creating the demand for new installations. However, a change in trend is noticeable in 2023, whereby a decrease in the growth rate from 69% to 43% (year-on-year) is observed. One reason for this change may be the limited form of support for future users of such an installation[8]. The figure below shows the annual increase in PV capacity by segment.

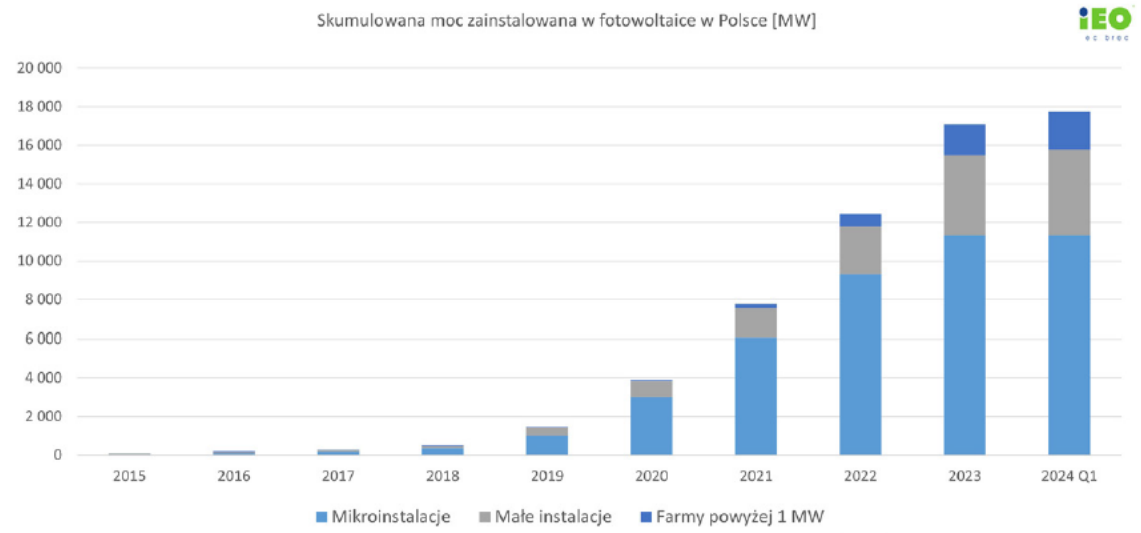

Figure 2. Annual growth of installed PV capacity in Poland. Source: 'Photovoltaic market in Poland. 12th edition, June 2024'

PV installations in Poland are responsible for the majority of the increase in power achieved by RES. The capacity achieved by PV in 2023 is 4.8 GW of which 1.9 GW are installations of prosumer

[7] URE data from may 2024 – Institute of Renewable Energy
[8] Instytut Energetyki Odnawialnej „Photovoltaic market in Poland. 12th edition, June 2024"

installations. At the end of 2023, the capacity of these installations was 10.7 GW. This consists of almost 1.4 million prosumer installations. In 2023, prosumer micro-installations accounted for approximately 66% of the total PV capacity. Installations of this type are mainly domestic, installed on service and commercial buildings owned by companies, as well as on religious buildings. There is also a noticeable increase in small installations, defined by the RES Act as installations up to 1 MW, which do not require a licence. The capacity of these installations represents approximately 24% of the total installed PV capacity. The total installed PV capacity consisted of installations, the breakdown of which was determined by their size. Micro installations with a total installed capacity of less than 50 kW amounted to 11.3 GW in 2023. In contrast, small installations whose capacity is between 50 and 1,000 kW reached a total capacity of 4.1 GW. PV farms, i.e. installations whose capacity exceeds 1 MW, reached a total installed capacity of 1.6 GW[8].

In the case of small micro-installations, a decrease is noticeable compared to 2022. The share of farms above 1 MW and small installations recorded increases. Despite the differences due to the number of new installations, PV installations again recorded a record increase in capacity. In 2023, 80 farms were connected to the grid with a total capacity of 0.77 GW[8].

At the beginning of 2024, photovoltaic installations accounted for 60% of the share of RES capacity. The systematic growth of new RES capacity is the same as the growth of green energy in the national electricity system.

A number of PV projects are being developed in Poland. Their total capacity is 17.05 GW, with large projects above 50 MW accounting for almost half of them. From a geographical point of view, the Wielkopolskie Voivodeship is the leader in the number of developed projects, with 557 projects. The voivodship also issued the largest number of building permits - 272 projects with a total capacity of 0.7 GW. The development of weather-dependent energy sources directly affects the stability of the electricity grid. Data from the Energy Regulatory Office shows that energy companies have reported more than 7,000 renewals of refusals to issue connection conditions. This is the highest number of refusals recorded in years[8].

- *Wind power industry*

Electric energy generated using wind is one of the key elements of Poland's energy mix and is expected to play an increasingly significant role in the future. With appropriate legislation and financial support, onshore wind farms could become the second-largest source of electricity production, surpassing the amount of energy generated from brown coal. In the update of Poland's Energy Policy, it is planned that by 2030, the installed capacity of turbines will reach 14.5 GW. In the Energy and Climate Plan, there are provisions for nearly 16 GW generated on land and about 6 GW from offshore wind farms. The Polish Wind Energy Association (PSEW) estimates that leveraging the full potential of wind energy could allow for achieving a capacity of approximately 18 GW by 2030.

A barrier to the development of wind energy are location restrictions imposed by Polish legislation. Provisions regarding a minimum distance from buildings of 700 meters instead of 500 meters have significantly reduced the number of possible installations. It is estimated that this has led to a decrease in potential installed capacity by about 60-70%. Amending the regulations to reduce the minimum distance from buildings to 500 meters would be beneficial, among other

things, for local governments due to increased revenues in local budgets from the construction of new wind farms. Reducing the distance from buildings to the mentioned 500 meters would increase the area available for wind turbine installation from 2% to 4% of Poland's territory.

Another limitation is the pace of issuing permits and decisions necessary for the construction of wind farms. Currently, the entire procedure takes about 10 years, although it could be shortened to 3 years. Direct lines and cable pooling have been included in the Energy Law; however, the related provisions require clarification to function effectively in the market. The industry also sees a need to intensify efforts related to the existing transmission infrastructure. To fully develop and utilize the potential of wind energy, well-thought-out actions related to network expansion are necessary, which would enhance connection capacities without burdening end consumers with the costs of infrastructure development.

In 2023, many initiatives were focused on supporting the development of offshore wind energy. Auctions for a total installed capacity at sea were set at 12 GW. By 2040, an increase in installed capacity to 18 GW is planned. At the beginning of 2024, PSE recorded records in electricity production, occurring on January 24 and February 3, when wind turbines were operating at a momentary capacity of 8,500 MW. The year 2023 brought resolutions concerning the location of offshore wind farm projects. The Ministry of Infrastructure initiated 11 proceedings, with a total of 132 applications for 11 areas. According to analyzed potential for installed capacity, a total of 9.4 GW can be installed.

Over the year, wind power capacity increased by 8.5%. Over 10 years, an increase of 6 GW has been recorded, a 156% increase.

The installed capacity in onshore wind farms reached production from wind energy, which rose from 12.3 TWh in 2019 to 22.1 TWh in 2023.

At the end of 2023, Poland has 1,413 installations with a total installed capacity of 9.56 GW[9].

Poland does not yet have functioning wind farms. However, a strategic project has been initiated to unlock Poland's potential in energy production offshore as well. The offshore wind farm project has been valued at PLN 40 billion. The estimated added value for Poland is PLN 178 billion. The launch of the project also means new jobs. It is estimated that offshore wind energy can provide up to 100,000 jobs. A wind turbine blade factory in Szczecin is planned to start in 2026. A wind tower factory is also to be built in the same city. Large-scale steel structures will be manufactured in Gdansk[9].

- *Water power industry*

Hydropower has its origins as far back as the 19th century. One of the first projects was a hydroelectric power station located on the Krutynia River. The inter-war period was a time when a number of hydroelectric power plants were built and Poland then became a leader in Central and Eastern Europe. In 1968 the most popular, and one of the largest, hydroelectric power plant in Poland was put into operation - Solina Hydroelectric Power Station on the San River. Among

[9] https://www.teraz-srodowisko.pl/publikacje/energetyka-wiatrowa-w-polsce-2024/teraz-srodowisko-publikacja-energetyka-wiatrowa-w-polsce-2024.pdf

hydroelectric power plants, there are several types that use water energy in different ways. The most important ones include:

- - Pumped storage power plants,
- - Run-of-river (turbine) power plants,
- - Wave and tidal power stations
- - Underground power plants [10].

It is estimated that hydropower resources in Poland amount to 13.7 TWh per year. However, the share of hydropower in the Polish system is currently around 3%[11]. There are a number of hydroelectric power plants in Poland that differ significantly in size from others. The largest hydroelectric power plants in Poland are presented below [12].

Name of power plant	Installed capacity [MW]	River/lake
Żarnowiec	716,00	Jezioro Żarnowieckie
Porąbka - Żar	500,00	Soła
Solina	200,00	Jezioro Solińskie
Żydowo	167,00	Jezioro Kamienne, Kwiecko
Włocławek	162,00	Wisła
Niedzica	92,75	Jezioro Czorsztyńskie
Rożnów	56,00	Dunajec
Koronowo	27,50	Brda
Dębe	21,18	Jezioro Zegrzeńskie
Tresna	21,00	Soła
Plichowice	13,25	Bóbr
Dychów	12,60	Bóbr
Porąbka	12,52	Soła
Wały Śląskie	9,72	Odra
Brzeg Dolny	9,70	Odra
Żur	9,00	Wda
Czchów	8,40	Dunajec
Myczkowce	8,32	San

Table 1. List of the largest hydroelectric power plants in Poland. Own elaboration based on[9]

Small hydropower plants are mainly located on small reservoirs or small rivers. Approximately 91% of existing and planned hydropower plants in Europe are small hydropower plants (SHPPs). They are characterised by a capacity of less than 10 MW. Power plants with a capacity of less than 1 MW are mostly owned by energy companies or industrial plants. In contrast, smaller facilities owned mainly by local communities or private investors[13]. There are more than 700 small hydropower plants in Poland, which account for about 0.5% of the installed capacity of the National Electricity System [14].

Among the advantages of hydropower plants is their flexible controllability. They can be easily started or stopped - depending on the needs. Hydroelectric power plants are an important

[10] https://e-magazyny.pl/baza-wiedzy/elektrownie-wodne-w-polsce-wszystko-co-musisz-o-nich-wiedziec/
[11] https://www.rynekelektryczny.pl/moc-zainstalowana-farm-wiatrowych-w-polsce/
[12] https://enerad.pl/wiedza/elektrownie-wodne-w-polsce/
[13] https://enerad.pl/wiedza/elektrownie-wodne-w-polsce/
[14] https://e-magazyny.pl/eksperckim-okiem/energetyka-wodna-w-2023-roku-podsumowanie-i-trendy-na-2024-rok/

element in the Polish energy mix as they make it possible to regulate power in the electricity grid. In addition to generating energy, hydroelectric power plants can also act as energy storage facilities, as exemplified by pumped storage power plants. These power plants release energy during peak hours. At times of lower demand, water is pumped into the upper reservoirs using surplus energy.

One of the challenges to be faced in the operation of hydropower plants is the variability of water flows. Increasingly frequent extreme weather events in the form of drought or heavy rainfall significantly affect the availability of water for power generation. A key issue therefore becomes the storage of water in retention reservoirs that will make it possible to mitigate the resulting fluctuations. Another challenge facing the Polish hydropower industry is the need to modernise existing power plants or build new facilities. Many of the facilities in operation are in need of repair and improvement. In addition to investing in the modernisation of operating power plants, it is also necessary to build new facilities that will allow Poland to meet the requirements set by the European Union related to the share of RES in the national energy mix. In 2022, an inter-ministerial team was established to prepare new pumped storage power plant projects, with a total capacity of up to 6 GW. Another challenge to be addressed is environmental issues. Hydroelectric power plants can have an environmental impact on river ecosystems, so every effort should be made already during investment planning to minimise this impact.

The year 2023 brought important news for the Polish electricity system. A decision was made to resume the 'Młoty' pumped storage power station project in Bystrzyca Kłodzka. This is the largest project of its kind to date. The power plant is to have a capacity of 1,050 MW[15]. The project is being carried out by PGE Polska Grupa Energetyczna in cooperation with the National Fund for Environmental Protection and Water Management. To date, a feasibility study has been prepared for the installation and an environmental impact report is being prepared. An application has also been submitted to the Polish Power Grid to determine the connection conditions for the storage facility. This investment will significantly support the functioning of the Polish power system and, as the study also indicated, the power plant will protect the region against flooding.[16]. The investment also represents new jobs. Construction is expected to be completed in 2030. An inventory of damming facilities carried out by the National Water Management Authority showed that there are more than 14,000 structures and damming devices located in Poland, but only 4.5% are used for energy production purposes[17]. Poland has considerable potential for hydroelectric power. However, it is necessary to ensure adequate financing in order to use the country's full potential. The development of Poland's hydroelectric power plants will significantly affect the stability of the electricity system and bring Poland closer to energy independence.

- *Geothermal power industry*

Geothermal energy is energy obtained from the depths of the earth in the form of hot water or electric steam. This energy is directly used as electricity for municipal use or in production processes, as well as for generating energy using dry steam or brine. It is obtained by drilling into naturally groundwater. Geothermal energy sources can be used for low-temperature and high-temperature. Water-based resources can be used to heat houses, greenhouses or can also be used in heat pumps. High-temperature electric sources are used to produce heat and electricity

[15] https://e-magazyny.pl/eksperckim-okiem/energetyka-wodna-w-2023-roku-podsumowanie-i-trendy-na-2024-rok/
[16] https://www.portalsamorzadowy.pl/inwestycje/budowa-elektrowni-szczytowo-pompowej-mloty,508641.html
[17] Raport: "Małe elektrownie wodne w Polsce"

in special installations. In Poland, geothermal waters filling rocks are located at a depth of 700 to 3,000 meters. Their temperature ranges from 20 to 100°C[18]. Poland has geothermal energy resources and has a potential of all geothermal energy sources, which is estimated at 1,512 PJ/year, which is 30% of the use of heat energy[19]. The conditions for the use of geothermal waters are located in the Podhale Basin, in the Grudziądz-Warsaw district and around Szczecin. An important application is that geothermal water resources are used in conditions located in areas overlapping with industrialized areas, with significant density of urban and rural agglomerations. There are also areas intended for agricultural cultivation. In areas where geothermal water resources occur, such as the city of Warsaw, Poznań, Płock, Toruń or Szczecin[20]. For this reason, the use of water for the production of heat energy is difficult. The map below shows the temperature distribution of geothermal resources at a depth of 3.000 m. In Poland in 2022, there were 7 geothermal energy switches[21]. The table below presents a list of geothermal water installations.

Name of the plant	Annual production [TJ]
Geotermia Podhalańska	562
G-Term Energy	208
Geotermia Pyrzyce	68
Geotermia Poddębice	63
Geotermia Uniejów	52
Geotermia Mazowiecka	16

Table 2. Geothermal heat production in 2019. Own study based on [11]

[18] https://www.mae.com.pl/oferta-mae/baza-wiedzy/odnawialne-zrodla-energii/energia-geotermalna
[19] http://www.pga.org.pl/geotermia-zasoby-polskie.html
[20] https://www.mae.com.pl/oferta-mae/baza-wiedzy/odnawialne-zrodla-energii/energia-geotermalna
[21] Forum Energii: „Geotermia – stabilny grunt w ciepłownictwie. Rola geotermii w transformacji sektora ciepła”

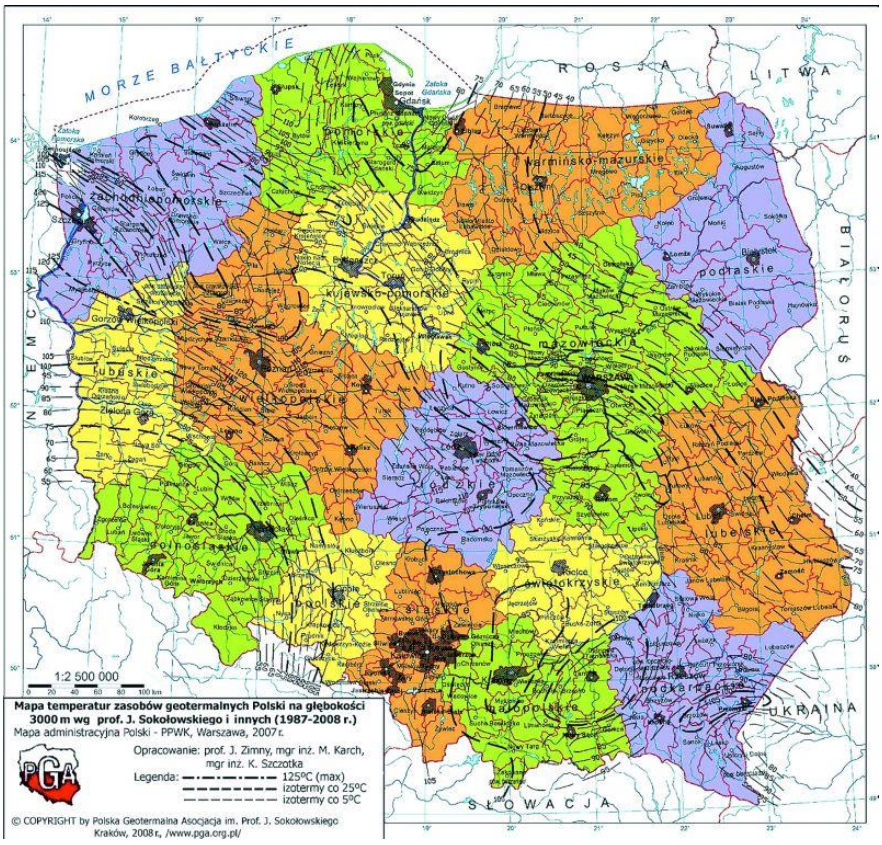

Figure 4. Temperature distribution map of geothermal resources at a depth of 3,000 m. Source: http://pga.org.pl/geotermia-zasoby-polskie.html

Thermal energy has the lowest share in obtaining renewable energy sources in Poland. It accounts for only 0.3% of the RES structure[22]. According to the report by the European Geothermal Energy Council published in 2020, Poland ranked 14th among European Union countries in terms of the number of geothermal systems[23]. In 2020, heat generated from geothermal sources amounted to 1.07 PJ, which represented 0.4% of the district heating supplied to consumers. The roadmap for geothermal development in Poland anticipates the expansion to 78 geothermal installations. By 2030, 58 expansion projects are to be realized, enabling a total capacity of 230 MWt to be achieved. These installations could collectively produce approximately 2.5 PJ of heat, which, when combined with existing installations, would account for 1.5% of the national district heating demand. Meanwhile, by 2040, an increase in the capacity of installations to 290 MWt is planned[24]. The main way of utilizing thermal waters is through district heating. This creates opportunities to reduce the emissions of this sector, which can lead to improvements in health and quality of life for society. In some cases, district heating plants have the option of implementing cogeneration, producing both heat and electricity. A key factor determining the sustainable operation of these systems is the reinjection of spent water and the monitoring of geothermal installation systems. The main issues observed during the operation of these systems are mainly corrosion and scaling caused by the mineral components present in thermal waters. The observed trends aimed at decarbonizing the economy by using clean energy carriers suggest that this technology will

[22] Informacja o wynikach kontroli NIK: Wykorzystanie energii wód termalnych dla celów wytwarzania ciepła

[23] B. Kępińska - Wykorzystanie energii geotermalnej w Polsce w latach 2019–2021

[24] Forum Energii: „Geotermia – stabilny grunt w ciepłownictwie. Rola geotermii w transformacji sektora ciepła”

continue to be developed in Poland, with more installations to emerge. This is evidenced by the fact that in recent years, a number of documents have been created (including the Strategy for Responsible Development and the assumptions of Poland's Energy Policy until 2040) related to the development of technologies that utilize thermal waters. Another argument supporting the justification for investing in this area is the positive functioning of the installations, high social acceptance, and the growing competitiveness of geothermal heat-based systems compared to those relying on conventional heat carriers. A key factor contributing to the further development of geothermal energy is the collaboration among various stakeholders in this sector—practitioners, scientists, entrepreneurs, decision-makers, local government officials, and financial institutions[25]. Following the report[26] geothermal energy could provide 720 PJ of heat by 2050, consuming 209 PJ of electricity. In comparison, generating the same amount of heat from natural gas or coal would require an energy input of 735 - 961 PJ. This would involve the consumption of 38 million tons of coal and 20 million m^3 of natural gas. Heat production from geothermal energy could contribute to savings of around 69 billion zlotys in costs related to CO_2 emissions.

LEGAL CONDITIONS

The issue of sustainable development, a key element of Polish environmental protection law, highlights the need to integrate political, economic, and social actions while maintaining ecological balance. These principles are also the foundation of spatial policy, which local government bodies and the central administration should shape to ensure harmonious socio-economic development that meets the needs of both present and future generations.

Recently, there have been changes in Polish legislation concerning renewable energy sources. In 2023, amendments were made to the law defining the locational possibilities of PV and wind systems. The amended legal acts are as follows:

- *Regulation of September 10, 2019, on projects likely to have a significant impact on the environment*

The purpose of the changes is to simplify the investment process for photovoltaic power plants (as well as facilitate the construction of garages and parking lots). The authors of the regulation point out that environmental impact assessments are unnecessary for projects that have a negligible or no impact on the surroundings, due to their nature and location. This applies especially to the construction of smaller photovoltaic power plants. Changes increase the surface area limit for photovoltaic installations that can be implemented outside protected areas. According to the new regulations, the requirement to obtain an environmental impact decision will apply to installations covering an area of 2 hectares, instead of 1 hectare, while PV systems installed on roofs and building facades will be exempt from this obligation. Additionally, the amendment to the Building Law increases the maximum power of photovoltaic installations that can be constructed without the need for a permit from 50 kW to 150 kW.

- *Act of October 3, 2008, on providing information on the environment and its protection, public participation in environmental protection, and environmental impact assessments*

[25] B. Kępińska - Wykorzystanie energii geotermalnej w Polsce w latach 2019–2021
[26] Forum Energii: „Geotermia – stabilny grunt w ciepłownictwie. Rola geotermii w transformacji sektora ciepła

One of the significant changes introduced by this law is the simplification of the procedure for obtaining environmental decisions for investments planned in landscape parks and areas of protected landscape. According to the Nature Conservation Act, the regional council may introduce a ban on implementing projects that could significantly affect the environment in these areas, based on local regulations. After the amendment, investors can apply for an environmental impact assessment if the project is located within the boundaries of landscape parks or protected landscape areas. If the investment does not comply with the local spatial development plan, the authority responsible for issuing the decision will refuse approval for its implementation. As a result, the procedure for obtaining environmental impact decisions for projects planned in these protected areas has been simplified.

- *Act of March 27, 2003, on spatial planning and development*

Its purpose is to simplify the regulations related to spatial planning and streamline the process of creating and adopting local legal acts related to municipal spatial planning. Under the new regulations, renewable energy installations may be located only based on a local spatial development plan if they are placed on: agricultural land of classes I-III and forest land; agricultural land of class IV if their installed capacity exceeds 150 kW or is used exclusively for electricity production within a business activity; other land if the installation's capacity exceeds 1 MW. This means that all large-scale photovoltaic installations will require the adoption of a local plan.

- *Act of May 20, 2016, on investments in wind power plants*

The initial development of wind energy was halted in the mid-2010s by the so-called distance law. It imposed restrictions on the placement of wind farms on more than 99% of Poland's territory and increased taxation on wind power plants. Additionally, the government kept the value of green certificates, the financial support system for renewable energy producers, at a reduced level. Since 2016, the system for new wind power plants (and other renewable energy sources) was changed from green certificates to auctions. However, the reference prices, which set the maximum level of support, were too low, and the unstable legal conditions caused wind energy development to become uncertain by the end of the last decade. Wind farm development resumed only after reducing taxes on generation facilities and offering better conditions for new investments under the 2018 renewable energy auctions. The 10H rule was liberalized in 2023. Currently, the minimum distance for locating wind power plants from buildings is 700 meters, compared to the previous distance of about 1.5 kilometers (depending on the height of the installation). However, this is still more than the announced 500 meters, which would have unlocked an additional 47% of the potential for onshore wind energy expansion, and the complicated planning process extends the investment period to up to 10 years. For many years, work on a support system for offshore wind energy was also delayed, which is only now starting to develop.

- *RED II - Act of August 17, 2023, Amending the Act on Renewable Energy Sources*[27]

On October 1, 2023, an amendment to the Renewable Energy Sources Act, introduced by the Act of August 17, 2023 (Journal of Laws of 2023, item 1762), came into force. This amendment is part of the implementation of further solutions contained in Directive (EU) 2018/2001 of the European Parliament and Council of December 11, 2018, known as RED II Directive, into Polish law. This directive promotes energy from renewable sources both in the electricity and heat markets, with

[27,9] Renewable Energy Directive (europa.eu)

the aim of increasing the share of RES in the national energy mix, reducing greenhouse gas emissions, and enhancing Poland's energy security.

Article 25(2) of RED II requires that greenhouse gas emissions reductions from using RFNBO (Renewable Fuels of Non-Biological Origin) must be at least 70% compared to fossil fuels. However, the directive does not specify the methodology for calculating this requirement. It is worth emphasizing that the RED II directive was partially implemented into Polish law by the Act of August 14, 2020, which amended, among others, the Act on Bio-components and Liquid Biofuels. The practice will show whether the new regulations and institutions launched in the amendment will meet their goals, or whether full implementation will take longer than expected by the legislature.

- *RED III* [28]

The RED III Directive, adopted in October 2023, represents a significant step in the European Union's energy transition, raising the target for the share of renewable energy to 42.5% by 2030. In comparison to the previous RED II, which set this target at 32%, the new directive reflects the growing challenges and ambitions of the EU regarding energy independence, CO_2 emissions reduction, and decreasing reliance on fossil fuel imports.

RED III not only establishes binding overall targets but also institutes specific goals related to heating, cooling, and other key sectors of the economy. In addition to the main target of 42.5%, an indicative target of 45% has also been adopted to further encourage member states to accelerate the implementation of renewable energy sources. During the vote on RED III, Poland was one of the few countries that did not support its adoption, reflecting concerns about the challenges in meeting these targets. Achieving these goals will require significant organizational and political effort.

The introduction of mandatory targets means that member states must adapt their legal frameworks to enable their implementation. Failure to meet these obligations could result in claims from other member states or EU institutions, and in extreme cases, proceedings before the Court of Justice of the European Union.

The amendment to the Renewable Energy Sources Act[29]

The Renewable Energy Sources Act (RES Act) in Poland has been a key legal framework promoting the development and utilization of renewable energy. The Act has undergone several amendments over the years to align with both domestic and European Union (EU) climate and energy goals. Here is an overview of the recent amendments and their significance:

- *Regulations on the Sale of Electricity from Renewable Sources*

Amendment clearly defines the rules for sale of electricity from renewable energy sources directly from the producer through Power Purchase Agreement (PPA) contracts. The established regulations govern issues related to concluding such agreements, which allow direct transactions between energy producers and consumers, eliminating intermediaries.

- *Support for the Development of Biomethane Use*

[29]Amendment to the RES Act adopted by the Council of Ministers - Ministry of Climate and Environment - Gov.pl website (www.gov.pl)

Amendment introduces a statutory definition of biomethane and expands the regulations on the legal framework for activities related to the production of biomethane or the production of biomethane from biogas. According to the new provisions, this activity is recognized as regulated and requires registration in the register of biogas producers, maintained by the President of the Energy Regulatory Office. Additionally, a new support system for biomethane producers has been introduced, based on a price premium, known as the feed-in premium (FiP).

- *Tenant Prosumer*

A new solution has been introduced regarding the use of renewable energy installations in multi-unit buildings through the establishment of the tenant prosumer institution. This solution introduces a new settlement method for renewable energy prosumers, allowing for a change in the form of compensation for the produced electricity. An individual prosumer, producing energy for the common areas of a multi-unit building, such as housing associations or cooperatives, gains the option to either reduce the electricity bill through a prosumer account or receive a payout for the value of the generated energy to their designated bank account.

- *Simplifications for Energy Clusters*

Amendment to the RES Act introduces significant improvements in the functioning of energy clusters to strengthen local energy security by intensively utilizing renewable energy sources and supporting local entrepreneurship and communities. The modified definition of energy clusters requires that they include at least one local government unit or a capital company associated with it. Specific criteria include:

- A capital company established by a local government unit under Article 9(1) of the Municipal Management Act of December 20, 1996 (Journal of Laws of 2021, item 679).
- A capital company in which the local government unit holds more than 50% of shares in the share capital or the number of shares.

Additionally, the amendment expands the scope of energy clusters by establishing a cluster registry and defining the rules for their cooperation with distribution system operators and energy sellers. A support system for energy clusters has also been introduced, offering discounts on distribution fees and charges related to renewable energy support systems, high-efficiency cogeneration, and energy efficiency. To benefit from these discounts, the cluster must be registered with the President of the Energy Regulatory Office (URE) and meet minimum requirements for renewable energy consumption, installed capacity in generation sources and energy storage, as well as covering its own electricity demand through its own production.

- *Support for Modernized Renewable Energy Installations*

New regulations on support for renewable energy installations aim to keep existing units in the system, especially those nearing the end of their eligibility for previous support systems after a 15-year period. The amendment to the Act broadens the definition of modernization, allowing further operation of the installations after appropriate modernization investments. The expanded definition of modernization includes:

- Restoration of the original condition or alteration of the operational or technical parameters of the renewable energy installation.
- Conversion of a renewable energy installation into another type of renewable energy installation, excluding conversion into a multi-fuel combustion installation.

- Conversion of a generating unit (as defined in the Energy Law) that is not a renewable energy installation into a renewable energy installation, excluding conversion into a multi-fuel combustion installation.

The legislator has stipulated that support will be available for installations that, after modernization, will remain operational, with investment costs amounting to at least 25% of the cost of building a new reference installation. Installations with an installed capacity of less than 500 kW can benefit from the Feed-in Tariff (FIT) system, while installations with a capacity between 500 kW and 1 MW can benefit from the Feed-in Premium (FIP) system. Additionally, modernized renewable energy installations will be able to participate in auctions for the sale of electricity. The amendment also stipulates that operational support will be allocated to installations capable of continuing operations for another 10 years, which incur operational costs that exceed revenues from the sale of energy at market prices. This applies to, among others, hydroelectric power plants (up to 5 MW), biomass, biogas, and waste-utilizing installations. Installations with a capacity above 1 MW will be covered by a support system based on auctions, while smaller installations (up to 1 MW) will be subject to the Feed-in Premium (FIP) system.

- *Shared Connection Infrastructure (Cable-Pooling)*

The amendment institutes a cable-pooling mechanism that enables the shared use of connection infrastructure by various renewable energy installations, such as wind and photovoltaic power plants. With this solution, it is possible to connect more than one renewable energy installation to a single connection point to the distribution system. Shared connection infrastructure is available for beneficiaries of support systems such as the auction support system, the Feed-in Tariff system, and the Feed-in Premium system. However, a necessary condition is that the electricity producer in the planned installation to be connected does not and will not use any other mechanism supporting the production of renewable energy. For installations operating within a hybrid renewable energy structure, it is planned to enter into a single contract with the grid operator. An important element of the amendment is also the safeguard against exceeding the permissible capacity by installations sharing the connection. In the event of exceeding this capacity, the grid operator will be entitled to charge additional fees.

Others regulation that influence RES development

- *Updated Regulations Concerning Heating and Cooling*

Provisions regarding the priority purchase of heat from renewable sources, waste incineration plants, and waste heat have been clarified. The new regulations specify the rules under which heat produced from these sources takes precedence over other forms of heat.

- *Extension of Guarantees of Origin*

The scope of issuance of guarantees of origin has been expanded to include types and carriers of energy such as biomethane, heat, and cooling from renewable energy sources, as well as renewable hydrogen. The new regulations also enable the Polish authority responsible for issuing guarantees of origin to join the international association, the Association of Issuing Bodies (AiB), with the goal of facilitating cross-border trade.

- *Establishment of a National Contact Point*

The National Contact Point for renewable energy sources will serve as an informational support for future producers of renewable energy. Its operation will be conducted online, providing easy

access to essential information and advice. The Ministry of Climate will be responsible for establishing and operating this point, which will streamline the process of obtaining information and support for individuals and companies interested in developing activities in the renewable energy sector.

- *Simplifications in Administrative Procedures*

Under previous Building Law regulations, installing photovoltaic devices, heat pumps, and free-standing solar collectors with an installed electrical capacity exceeding 50 kW required obtaining a building permit. As a result of the amendment, the threshold for electrical capacity requiring such a decision has been raised to 150 kW.

- *Facilitation for Energy Cooperatives*

Regulatory changes include expanding the area where cooperatives can operate and modifying their definitions. The amendment also implements changes to the discounts available to energy cooperatives, along with new obligations for distribution system operators and energy sellers in their interactions with cooperatives. Additionally, reporting conditions and settlement rules have been simplified.

- *Operational Support (Continuation) for Renewable Energy Installations*

A new support system has been created for energy producers exploiting installations that are in good technical condition and are able to continue operating. These provisions are mainly targeted at energy producers using biogas, biomass, and small hydropower plants that are exiting the certificate of origin system. These producers often face operational costs higher than their revenue from selling energy at market prices, making continued operation of these installations difficult. However, the Ministry of Climate has noted that the implementation of this support system has been postponed until mid-2025 due to the currently high energy prices.

- *New Definition of Hybrid Renewable Energy Installations*

The new definition includes the requirement to launch an energy storage facility as an integral part of such installations. Additionally, the amendment introduces a new definition of installed electric capacity for renewable energy installations, specifying the total rated active power for hybrid renewable energy installations. This will enable more precise monitoring and regulation of their operation.

- *Support for Offshore Wind Energy*

Ministry of Climate emphasizes that the latest changes in the legislation concerning offshore wind energy aim to increase the efficiency of planning and implementing infrastructure in this sector. Key changes include primarily increasing the auction volumes for energy from offshore wind farms from the current 5 GW to 12 GW within the period of 2025-2031. Additionally, the regulations concerning the procedure for submitting applications for the connection of power from offshore wind farms have been updated and clarified, which should simplify and accelerate the process of connecting them to the power grid.

DETERMINANTS OF DEVELOPMENT

The implementation of investments related to PV and elevator installations requires a number of administrative decisions: a decision on development conditions, a decision on environmental

conditions, a decision on a building permit. The spatial planning system also plays an important role.

The development of renewable energy sources in Poland is influenced by a mix of economic, political, social, and environmental factors. Poland, traditionally reliant on coal for energy, is now transitioning to a more sustainable energy mix due to both domestic and international pressures.

- *Government policies and regulatory framework*

The development of renewable energy sources in Poland is strongly influenced by national policies, regulations, and international commitments, particularly those set by the European Union. These frameworks shape both the strategic direction and pace of renewable energy deployment in the country. The key components of this framework include EU directives, Poland's own energy policy, and various support schemes aimed at encouraging investment in renewables.

As a member of the European Union, Poland is required to comply with various climate and energy directives that set binding targets for reducing greenhouse gas (GHG) emissions and increasing the share of renewable energy in the overall energy mix. The EU's overarching goals for climate neutrality by 2050 and significant emissions reductions by 2030 are major drivers of Poland's energy transition. One of the most significant EU policies is the European Green Deal[30], which aims for Europe to become the first climate-neutral continent by 2050. It mandates substantial investments in clean energy, including renewable energy sources, and requires member states like Poland to phase out coal and other fossil fuels. Fit for 55 Package[31] initiative sets a goal of reducing GHG emissions by 55% by 2030 compared to 1990 levels. To achieve this, the EU has introduced legislation that pushes member states toward higher shares of renewable energy in their national energy mixes. Poland, with its historically high reliance on coal, faces one of the steeper challenges in meeting these targets, making compliance with EU regulations a driving factor for renewable energy development. Renewable Energy Directive (RED II)[32] sets specific targets for renewable energy adoption within the EU. The directive mandates that 32% of the EU's final energy consumption come from renewable sources by 2030. Poland's obligations under this directive compel the country to increase its share of renewable energy, particularly in electricity, heating, cooling, and transport sectors. To achieve this, Poland is required to create favorable regulatory environments for renewable energy development, which includes simplifying permitting processes, providing incentives for renewable energy projects, and promoting energy storage technologies.

Poland's own long-term energy strategy, known as Poland's Energy Policy until 2040[33] (PEP 2040), outlines the country's plans for transforming its energy sector in alignment with EU climate and energy goals. The key focus areas of this policy are reducing coal dependency, increasing the share of renewables, and ensuring energy security. PEP 2040 sets a target of increasing the share of renewables in gross final energy consumption to 23% by 2030, with specific goals for various sectors. One of the targets is to derive at least 32% of electricity from renewable sources by 2030, mainly through solar photovoltaics and wind power, including offshore wind farms in the Baltic Sea. The aim is also to increase the share of renewables in heating and cooling to 28.4% by 2030, primarily through biomass, heat pumps, and solar thermal energy. Moreover, in line with the EU Renewable Energy Directive, Poland aims to increase the share of renewables in the transport

[10,30] The European Green Deal - European Commission (europa.eu)
[31,13,14] Renewable Energy Directive (europa.eu), Energy Regulatory Office (ure.gov.pl)

sector, including biofuels and electric vehicles (EVs). One of the most contentious aspects of PEP 2040 is the gradual phase-out of coal, which has traditionally been a cornerstone of Poland's energy system. By 2040, coal's share in electricity generation is expected to fall below 30%, down from over 70% in 2020. While this transition poses significant social and economic challenges, particularly in coal-dependent regions like Silesia, it also opens up opportunities for renewable energy expansion.

To promote the development of renewable energy, Poland has introduced a range of support mechanisms, such as auctions, subsidies, and tax incentives. These schemes are essential to attracting investments, ensuring the economic viability of RES projects, and fostering growth in renewable sectors like wind, solar, and biomass. Poland has adopted a competitive auction system for renewable energy producers. In these auctions, developers bid for long-term contracts to supply electricity from renewable sources. The winners are awarded contracts based on the lowest offered price per unit of electricity. This system ensures that only the most cost-efficient projects are awarded contracts, while also providing guaranteed revenues for developers. The auction mechanism has been particularly successful in promoting solar energy and wind power, with large-scale solar and onshore wind projects benefiting from these auctions. For smaller renewable energy producers, Poland has implemented feed-in tariffs and feed-in premiums, which guarantee fixed or market-adjusted prices for electricity generated from renewable sources. This system provides financial security to smaller producers, particularly in the solar PV sector, where residential and small commercial installations have grown significantly in recent years. The Mój Prąd[34] (My Electricity) program has been a major driver of rooftop solar installations, leading to a rapid increase in decentralized renewable energy production. Poland's net metering system allows prosumers to offset the cost of the electricity they consume by feeding excess electricity from their renewable systems (e.g., solar PV) back into the grid. This system incentivizes private investment in renewable energy by providing households and businesses with savings on their electricity bills.

Furthermore, Poland receives significant financial support from the European Union through various structural and cohesion funds. These funds are allocated to modernize the energy sector, invest in clean technologies, and support the energy transition in coal-dependent regions. EU funds are critical for financing large-scale renewable energy projects, particularly offshore wind farms in the Baltic Sea, as well as energy storage and grid modernization efforts.

One of the barriers to renewable energy development in Poland has been the complexity and length of the permitting process for renewable energy projects. To address this, the government has introduced reforms aimed at streamlining administrative procedures and reducing bureaucratic hurdles. A particularly controversial regulation in Poland has been the "10H rule", which was introduced in 2016. This law required wind turbines to be located at a distance of at least 10 times the height of the turbine from the nearest residential building, effectively freezing onshore wind development in many parts of the country. In response to growing pressure from the renewable energy sector and EU climate goals, the Polish government has recently worked on revising this law to allow more flexibility and enable the development of new onshore wind projects. The government has also implemented measures to make it easier for renewable energy projects to connect to the national grid. This includes simplifying the process for obtaining grid connection permits and encouraging investments in grid infrastructure, which is necessary to accommodate the increasing share of intermittent renewable energy sources like wind and solar.

[34] Mój Prąd (mojprad.gov.pl)

- *Economic factors*

Economic factors play a significant role in determining the pace and scale of renewable energy development in Poland. These factors include the cost of renewable energy technologies, the structure of the energy market, access to investment capital, and economic incentives that can make renewable projects more financially attractive. Poland's energy transition is influenced by both the falling costs of renewable energy technologies and the need to attract domestic and foreign investments to replace coal with cleaner energy sources.

The initial costs of renewable energy technologies, particularly for large-scale projects like wind farms and solar power plants, have historically been a major barrier to widespread adoption in Poland. However, these costs have been falling steadily over the past decade, making renewables more competitive with traditional fossil fuel-based energy sources. Solar photovoltaic (PV) systems and wind turbines have seen significant reductions in cost due to technological advancements, economies of scale, and increased global production. As a result, the levelized cost of electricity (LCOE) from renewables is now often lower than that of coal and gas-fired power plants, particularly for onshore wind and solar PV projects.

While offshore wind projects require higher initial investments due to the complexity of installation and grid connection, they hold great potential for Poland. The Baltic Sea offers favourable conditions for offshore wind farms, and as the costs of offshore wind technology decrease, these projects are becoming more economically viable. The Polish government has recognized the potential of offshore wind and has committed to developing this sector as part of its energy transition strategy.

One challenge for renewable energy is the intermittent nature of wind and solar power. Energy storage systems, such as batteries, are essential for managing variability and ensuring a stable electricity supply. While the cost of energy storage is still relatively high, it has been decreasing, and advancements in storage technologies will likely make renewable energy more reliable and scalable.

Poland's energy market has been historically dominated by coal, with large state-owned energy companies controlling the majority of the power generation and distribution infrastructure. This concentration of power in the hands of a few major players has influenced the speed of the energy transition. The traditional dominance of coal-fired power plants in Poland's energy sector has created resistance to rapid changes, as many state-owned companies and labour unions are tied to the coal industry. The phasing out of coal, while necessary for meeting EU climate goals, requires significant restructuring of the energy market, including the development of new business models for renewable energy. Greater liberalization of the energy market, which allows private companies and independent power producers to participate more actively, is key to accelerating renewable energy growth. As the market opens up to more competition, renewable energy developers have more opportunities to enter the market and invest in clean energy projects. Moreover, the cost of electricity in Poland has been rising in recent years, partly due to the rising costs of carbon emissions under the EU Emissions Trading System (ETS)[35]. As coal-fired power plants become more expensive to operate due to carbon pricing, renewables are becoming a more attractive alternative both for large utilities and independent power producers.

Attracting both domestic and foreign investments is essential for financing the large-scale infrastructure projects required for Poland's energy transition. The renewable energy sector is

[35] EU Emissions Trading System (EU ETS) - European Commission (europa.eu)

capital-intensive, particularly for projects like offshore wind farms, large-scale solar parks, and energy storage facilities. Poland is one of the largest recipients of EU funds, which are increasingly directed toward green projects. EU programs such as the Recovery and Resilience Facility and the European Investment Bank's climate initiatives provide financial backing for renewable energy development, including grid modernization and clean energy innovation.

To further stimulate renewable energy growth, Poland has encouraged public-private partnerships (PPPs). These partnerships involve collaboration between government entities and private investors to finance, build, and operate renewable energy projects. PPPs are particularly important for financing large infrastructure projects like offshore wind farms and smart grid development. There is growing interest in green bonds and other forms of sustainable finance, which are used to raise capital for environmentally friendly projects. Polish companies and financial institutions have started to issue green bonds to finance renewable energy projects, signalling a shift toward more sustainable investment strategies.

Renewable energy development also has positive economic impacts through job creation and regional development. As Poland moves away from coal, the renewable energy sector offers opportunities for new jobs in manufacturing, installation, maintenance, and research and development (R&D). The renewable energy sector is labour-intensive, particularly during the construction and installation phases of wind farms, solar plants, and energy storage systems. As Poland scales up its renewable energy projects, the demand for skilled labour in the green energy sector is expected to grow, providing new employment opportunities, especially in regions affected by coal phase-out. Renewable energy projects, especially in less developed or coal-dependent regions, can drive economic diversification. For example, regions that have historically relied on coal mining may benefit from the development of wind or solar farms, leading to new economic activities and increased local investment.

- *Natural resources and geographic conditions*

Poland's natural resources and geographic conditions are key determinants of the country's renewable energy potential. The availability of wind, solar, and biomass resources, as well as the country's physical geography, significantly influence the development of renewable energy projects. These resources vary across regions, creating opportunities for tailored renewable energy strategies in different parts of Poland.

Wind energy is one of the most promising renewable energy sources in Poland, particularly in the northern regions and the Baltic Sea. Poland has strong onshore wind potential, especially in the northern and central regions of the country, where wind speeds are higher and more consistent. Areas like Pomerania, Masuria, and the northern coastal regions have become hubs for onshore wind farm development. However, the expansion of onshore wind has been hindered by restrictive regulations, notably the "10H rule". The Baltic Sea offers significant potential for offshore wind farms due to its relatively shallow waters, favourable wind conditions, and proximity to key population centres. Offshore wind development is a key pillar of Poland's renewable energy strategy, with plans to install up to 11 GW of offshore wind capacity by 2040. The Baltic Sea's wind resources are seen as a major driver of future renewable energy growth in Poland, with multiple large-scale projects already in development, such as the Baltica Wind Farm.

Poland has a moderate solar energy potential, with most of the solar resources concentrated in the southern and central parts of the country. While Poland's solar insolation levels are not as high as those in Southern Europe, solar power still offers considerable opportunities, particularly for decentralized energy production. The best solar energy potential is found in regions such as Lower

Silesia, Greater Poland, and the Mazovia region, where sunlight hours are more consistent. These areas have seen a rapid increase in the installation of photovoltaic panels, both for large-scale solar farms and small-scale rooftop installations. Moreover, rooftop solar PV installations have experienced significant growth. The relatively low costs of solar PV technology, combined with government support, have made solar energy one of the fastest-growing renewable sectors in Poland.

Poland's large agricultural and forestry sectors provide substantial biomass resources for renewable energy production. Biomass is used primarily for heating and electricity generation and is seen as an important part of Poland's renewable energy mix, particularly in rural areas. The country's extensive agricultural activities produce large amounts of agricultural waste and residues, such as straw, manure, and crop by-products, which can be used for biomass energy. This is particularly important in rural regions where biomass plants can contribute to local energy production and create economic opportunities for farmers. Poland's forests also offer a significant source of biomass, particularly wood chips, pellets, and other forestry residues. Biomass from forestry is often used in combined heat and power (CHP) plants, providing both electricity and heating to local communities. Biomass energy is considered a relatively stable and reliable renewable source compared to intermittent sources like wind and solar.

Poland has limited potential for large-scale hydropower due to its relatively flat terrain and the absence of large, fast-flowing rivers. However, there are several small and medium-sized hydropower plants operating across the country, mainly in the southern mountainous regions. Poland's small hydropower plants are concentrated in areas with rivers and streams that can support energy generation without the need for large dams or reservoirs. While hydropower is not a major part of Poland's energy strategy, it still contributes a small share to the country's renewable energy mix, especially in regions where other renewable resources may be less viable.

- *Social Acceptance and Public Perception*

The development of renewable energy in Poland is also heavily influenced by social acceptance and public perception. The level of public support, local community engagement, and the perceived impact of renewable energy projects on residents' lives play a critical role in determining the success or opposition to these projects. Renewable energy initiatives that consider the interests of local communities and effectively communicate the benefits of clean energy tend to encounter less resistance and gain broader acceptance.

In general, public support for renewable energy in Poland is strong, driven by increasing awareness of environmental issues, energy security, and the economic benefits of clean energy. Many Poles recognize the need to transition away from coal and other fossil fuels, particularly as concerns about air pollution and climate change grow. Air quality in Poland is among the worst in Europe due to the widespread use of coal for heating and electricity generation. Public awareness of the health impacts of air pollution, particularly in coal-dependent regions, has led to stronger support for renewable energy. The Polish public is increasingly aware of the environmental and health benefits associated with wind, solar, and biomass energy, which emit significantly fewer pollutants than coal-fired power plants. The public's perception of energy security, especially amid rising energy prices and geopolitical tensions, also plays a role in shaping attitudes toward renewables. Many Poles view renewable energy as a way to reduce dependence on imported fossil fuels and increase Poland's energy independence, particularly in light of energy supply concerns related to Russia and global energy markets.

Despite overall public support, renewable energy projects, especially large-scale developments, sometimes face opposition from local communities. This resistance often stems from concerns about the visual, environmental, and economic impacts of such projects. Onshore wind farms, in particular, have faced resistance in some rural areas due to the perceived negative impact on landscapes, property values, and noise pollution. The mentioned before "10H rule", which restricts wind turbine placement near residential areas, was implemented largely in response to local opposition to wind farms. This regulation has significantly slowed the development of onshore wind, though there are ongoing efforts to reform it to strike a better balance between community concerns and renewable energy goals.

In coal-dependent regions like Silesia, where the coal industry has been a major source of employment, there is resistance to renewable energy due to fears of job losses in mining and coal-related sectors. Many workers and communities in these regions are concerned that the transition to renewables will lead to economic decline and unemployment unless alternative job opportunities are created. The government has been working to address these concerns by promoting the Just Transition initiative, which aims to support retraining and economic diversification in coal-reliant areas.

Effective community engagement and the demonstration of local benefits are essential for increasing acceptance of renewable energy projects. Media coverage and political discourse around renewable energy also shape public perception. Support from political leaders and positive media portrayals of renewable energy projects can significantly influence how the public views the energy transition. The stance of political parties and leaders on renewable energy plays a crucial role in shaping public attitudes. In Poland, while there is broad support for renewable energy, political debates often focus on the economic costs of the transition and the future of the coal industry. Political parties that emphasize job creation in renewable energy sectors and energy independence tend to garner more public support for renewable initiatives. Positive media coverage of successful renewable energy projects, such as large-scale solar farms or offshore wind developments, helps foster public enthusiasm for clean energy. On the other hand, media coverage that highlights conflicts or failures, such as community opposition to wind farms or project delays, can contribute to scepticism and resistance.

- *Technological advancements*

Technological advancements play a crucial role in driving the development and efficiency of renewable energy sources in Poland. Innovations in renewable energy technologies, grid management, and energy storage are essential to overcoming the challenges posed by the intermittent nature of renewable sources like wind and solar power. Moreover, advancements in renewable energy technology can reduce costs, increase efficiency, and enhance the integration of renewable sources into the existing energy infrastructure.

Wind energy is one of the cornerstones of Poland's renewable energy strategy, and technological improvements in wind turbines and related infrastructure have made wind power more efficient and cost-effective. Technological advancements have led to the development of larger and more powerful wind turbines. Modern turbines are more efficient at capturing wind energy, even in areas with lower wind speeds, which increases the viability of wind energy in a broader range of geographic locations. This is particularly relevant for Poland, where northern coastal areas offer high potential for wind energy but other regions may have less ideal wind conditions. Offshore wind technology has made significant strides in recent years, allowing for the construction of wind farms in deeper waters with higher and more consistent wind speeds. Poland is investing heavily

in offshore wind projects in the Baltic Sea, and advancements in floating turbines and more durable materials are key to making these projects viable. These technological improvements help reduce maintenance costs and increase the lifespan of wind farms, which enhances their overall economic feasibility.

Solar energy technology has seen rapid advancements in recent years, particularly in the areas of efficiency, cost reduction, and storage solutions. Technological improvements in PV cells have led to increased energy conversion efficiency, meaning that solar panels can now generate more electricity from the same amount of sunlight. This is especially important for Poland, where solar insolation levels are moderate compared to southern European countries. Advances in monocrystalline and polycrystalline solar panels, as well as the development of thin-film technologies, have made solar energy more accessible and cost-effective. One of the main challenges with solar energy is its intermittency, as sunlight is only available during the day. Technological advancements in energy storage, particularly in battery systems, allow for the excess electricity generated during sunny periods to be stored and used when solar power is not available. The development of lithium-ion batteries and other energy storage technologies is crucial for integrating more solar energy into Poland's power grid, especially for small-scale installations and prosumers.

Biomass remains an important part of Poland's renewable energy mix, particularly in rural areas. Technological advancements in biomass conversion processes and combined heat and power systems have improved the efficiency and sustainability of bioenergy production. Modern biomass technologies, such as gasification and pyrolysis, have increased the efficiency of converting biomass into energy. These processes result in higher energy yields and lower emissions compared to traditional combustion methods. Such innovations make biomass a more attractive option for both electricity generation and heating, particularly in rural and agricultural regions of Poland, where biomass resources are abundant. Technological improvements in biogas plants have enhanced the ability to produce energy from organic waste materials, including agricultural residues and municipal waste. Anaerobic digestion technologies are becoming more efficient, enabling the generation of biogas that can be used to produce electricity, heat, or even converted into biomethane for use as a renewable natural gas substitute.

As Poland increases its reliance on renewable energy, the country's energy grid must be modernized to handle the variability of sources like wind and solar. Technological advancements in grid management, smart grids, and digitalization are essential for ensuring a stable and resilient energy system. Smart grid technology is key to integrating renewable energy into Poland's power system. A smart grid uses advanced sensors, communication technologies, and automation to manage electricity supply and demand in real-time. This allows for better balancing of intermittent renewable sources with electricity consumption, improving overall grid stability. Smart grids also enable the integration of distributed energy resources (like small-scale solar installations) and support the development of decentralized energy systems, which are becoming more common in Poland.

The development of large-scale energy storage systems, such as grid-scale batteries and pumped hydro storage, is crucial for ensuring the reliability of Poland's renewable energy supply. These technologies allow excess renewable energy to be stored during periods of low demand and released when demand is higher or renewable generation is low. Energy storage systems also provide grid operators with the flexibility needed to manage fluctuations in electricity supply from variable renewable sources.

Digitalization and the use of artificial intelligence (AI) are transforming the way renewable energy systems are managed and optimized. These technologies can help predict energy production, optimize energy use, and reduce operational costs for renewable energy projects.

AI and machine learning are being used to monitor and predict the maintenance needs of renewable energy installations, such as wind turbines and solar panels. Predictive maintenance technologies can identify potential issues before they cause equipment failures, reducing downtime and maintenance costs. This is particularly valuable for offshore wind farms, where maintenance can be costly and logistically challenging. AI is also improving energy forecasting, which helps grid operators better predict the output of renewable energy sources based on weather patterns and other variables. Improved forecasting allows for more accurate balancing of electricity supply and demand, reducing the need for backup power from fossil fuels and improving the overall efficiency of the energy system.

- *Environmental concerns and climate change*

Environmental concerns and the growing urgency to address climate change are key drivers behind Poland's push towards renewable energy development. The environmental impacts of continued reliance on fossil fuels, particularly coal, have made the transition to clean energy sources an important part of Poland's energy policy. As Poland faces pressures both domestically and from the international community to reduce greenhouse gas emissions and improve air quality, renewable energy sources provide a sustainable alternative to traditional fossil fuels.

Poland has long struggled with severe air pollution, largely due to its heavy reliance on coal for electricity generation and residential heating. Poland is one of the most coal-dependent countries in Europe, and coal-burning in power plants and home furnaces contributes significantly to air pollution, including high levels of particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). These pollutants are directly linked to serious health issues, such as respiratory diseases, cardiovascular problems, and premature deaths. Cities in southern Poland, like Kraków and Katowice, regularly experience some of the highest levels of air pollution in Europe, leading to growing public concern. By replacing coal with renewable energy sources like wind, solar, and biomass, Poland can significantly reduce harmful emissions. Wind and solar power generate electricity without emitting air pollutants, which helps to improve air quality and reduce the health impacts associated with coal burning. This is especially important as the public becomes more aware of the links between energy production, air pollution, and health.

The need to combat climate change is another critical factor driving the development of renewable energy in Poland. As a member of the European Union, Poland is required to contribute to the EU's ambitious climate goals, including achieving carbon neutrality by 2050 and reducing greenhouse gas emissions by 55% by 2030 under the mentioned before European Green Deal[36] and the Fit for 55 package[37]. These targets place significant pressure on Poland to transition away from fossil fuels and increase the share of renewable energy in its energy mix. Meeting these targets is crucial not only for Poland's international obligations but also to mitigate the long-term impacts of climate change on ecosystems, agriculture, and public health.

[36,18,19] The European Green Deal - European Commission (europa.eu), The Paris Agreement | UNFCCC

Renewable energy sources such as wind, solar, and biomass are key to reducing Poland's greenhouse gas emissions. Unlike coal or natural gas, renewable energy technologies produce little to no direct carbon emissions during electricity generation. By increasing the share of renewables, Poland can reduce its carbon footprint and contribute to global efforts to limit global warming to 1.5°C, as outlined in the Paris Agreement[38].

In addition to mitigation, Poland also needs to adapt to the effects of climate change, which include more frequent extreme weather events, such as heatwaves, floods, and droughts. Renewable energy sources can contribute to a more resilient energy system in the face of climate change. Decentralized energy systems, such as small-scale solar installations and distributed wind farms, can reduce vulnerability to extreme weather events that might disrupt centralized, coal-based energy grids. Moreover, advancements in energy storage and smart grid technologies allow for better management of energy supply and demand during extreme weather conditions, improving overall energy security. Coal power plants, in particular, require large amounts of water for cooling, which makes them vulnerable during periods of drought or extreme heat. Renewable energy technologies like wind and solar, on the other hand, require minimal water for operation, making them better suited for a future with more unpredictable weather patterns and water shortages.

While renewable energy offers significant environmental benefits, the development of large-scale renewable projects also raises concerns about land use and biodiversity. Wind farms, solar parks, and biomass production require substantial land area, which can sometimes lead to conflicts with other land uses, such as agriculture, forestry, or conservation areas. In Poland, the location of wind farms, in particular, has been controversial in some rural areas due to concerns about visual impacts, noise, and the disruption of local landscapes. Renewable energy projects, particularly wind and hydropower, can also have impacts on local ecosystems and wildlife. For instance, wind turbines have been linked to bird and bat fatalities, while poorly planned hydropower projects can disrupt aquatic habitats. To mitigate these impacts, it is essential to implement environmental impact assessments (EIAs) and adopt best practices in the planning and construction of renewable energy infrastructure. In Poland, ensuring that renewable energy development aligns with biodiversity conservation goals is a growing focus for both policymakers and developers.

- *Coal industry transition*

The transition of Poland’s coal industry is one of the most critical and challenging aspects of the country’s energy transformation. Poland has long been heavily reliant on coal for electricity generation and industrial energy needs, making it one of the most coal-dependent countries in Europe. However, with increasing environmental and economic pressures, Poland faces the difficult task of reducing its coal use while ensuring energy security, protecting jobs, and supporting affected regions.

Coal has played a central role in Poland’s economy and energy system for decades. At its peak, coal was the backbone of Poland’s industrialization, providing affordable energy for industries and creating a significant number of jobs in mining regions, particularly in Upper Silesia. Even today, Poland produces the majority of its electricity from coal, and the country is home to some of the largest lignite mines in Europe. Historically, coal provided Poland with a sense of energy independence and security, as the country has abundant coal reserves. Coal mining has also

been a major source of employment, particularly in the regions of Silesia, Lower Silesia, and Lubusz, which are heavily reliant on mining for economic stability. The coal sector has thus had a strong political influence, with workers and unions advocating for the protection of jobs and resisting rapid change. The coal industry in Poland is deeply tied to national identity and the working-class culture of mining regions. This cultural significance has made it politically sensitive to phase out coal, as any rapid shift away from coal threatens not only energy security but also the livelihoods of thousands of workers. As a result, managing the coal transition has required careful balancing of economic, social, and environmental priorities.

While coal has long been the foundation of Poland's energy system, the industry has faced increasing economic challenges in recent years. The economic viability of coal in Poland has been steadily declining due to a combination of factors, including the rising costs of maintaining aging coal power plants, decreasing demand, and increasing operational costs. Many coal mines in Poland are deep and expensive to operate, and they face competition from cheaper coal imports, particularly from Russia and Colombia. This has led to financial losses for state-owned coal companies, forcing the government to provide subsidies to keep some mines operational. The European Union Emissions Trading System (EU ETS)[39] has made coal power more expensive due to the increasing cost of carbon allowances. As the price of carbon permits rises, coal-fired power plants must pay more to emit greenhouse gases, making coal-generated electricity less competitive compared to renewables and natural gas. This has been a major economic driver pushing Poland toward renewable energy and the gradual phase-out of coal.

The Polish government has committed to a gradual phase-out of coal, although the timeline and scale of this transition are still under debate.

The transition away from coal poses significant challenges for workers in Poland's mining sector and coal-dependent communities. The coal industry in Poland employs tens of thousands of people, and the closure of mines and coal-fired power plants could lead to widespread job losses, particularly in regions like Upper Silesia. High unemployment and social unrest are real risks if the transition is not managed carefully, as many workers have limited opportunities for retraining or employment in other sectors. The Polish Mining Group (PGG), the country's largest coal company, has already reduced its workforce, and more layoffs are expected as the industry declines. Trade unions representing coal miners have historically been powerful political actors in Poland, often resisting efforts to close mines and reduce coal production. Miners' protests and strikes have occasionally erupted in response to government plans to phase out coal, and unions continue to lobby for the protection of coal jobs. The government has worked to balance these concerns by negotiating long-term coal phase-out agreements that provide miners with financial compensation, early retirement options, or opportunities for retraining.

Renewable energy development is seen as a key component of Poland's coal transition, providing an alternative energy source that can replace coal while also creating new jobs in clean energy sectors.

In summary, Poland's renewable energy sector is shaped by a complex interplay of government policies, economic factors, natural resources, technological advancements, and public attitudes. While the country faces challenges, such as its historical dependence on coal and regulatory hurdles, there are significant opportunities for growth, particularly in offshore wind,

[39] EU Emissions Trading System (EU ETS) - European Commission (europa.eu)

solar power, and biomass. The pace of Poland's energy transition will depend on how effectively it can harness these determinants and overcome existing barriers.

BARRIERS TO THE DEVELOPMENT OF RES

The first and fundamental factor is the lack of appropriate legal regulations, or the ambiguity and lack of precision in existing provisions of laws and regulations. The failure to issue executive acts for the Renewable Energy Sources Act and the Energy Law regarding the activities of prosumers and energy cooperatives is an obstacle to the uniform and favorable application of the law for these entities[40].

Another important and frequently discussed issue is the poor condition and underfunding of the power grid, which directly affects its efficiency and can lead to network overload when additional renewable energy sources are connected. The power grid in Poland has been adapted from the beginning for operation in a centralized generation structure. Integrating energy production from thousands of photovoltaic systems of varying installed capacities into such a grid creates stability issues and exacerbates the problem of limiting access to the network[41].

Another problem consists of the adequate distribution infrastructure, inter-system connections, and long-distance transmission [bariery rozwoju OZE]. Access to the power grid, for example for new photovoltaic sources, still constitutes one of the key challenges for the development of the renewable energy sector in Poland. In the context of the dynamically growing number of new renewable energy installations, the power system encounters infrastructural and regulatory barriers that hinder and, in extreme cases, prevent the effective integration of new sources of energy into the grid. Limited connection possibilities of the power grids in many regions of Poland result in a sharp increase in the number of refusals to issue connection conditions for new installations. According to development plans, by 2020 the capacity of inter-system connections must increase, which will require a comprehensive increase in the mutual connection capacity by 40%, and after that date, further integration must take place[42].

The transformation of the energy system to incorporate renewable energy sources (RES) also presents certain barriers and limitations. By 2030, all decarbonization scenarios propose increasing the share of renewable energy sources to around 30% of gross final energy consumption. Issues with the lack of connection capacity for RES are generating increasing challenges for new projects, particularly in the photovoltaic sector[43]. A challenge for Europe is also enabling market participants to maintain low costs of renewable energy through streamlined research, industrialization of the supply chain, more effective policies, and more efficient support systems. This may necessitate an increase in the convergence of support systems and greater accountability for system costs not only on the part of transmission system operators (TSOs) but also from producers. According to current regulations, energy companies involved in the transmission and distribution of electricity are required to publish information about entities applying for connection of sources to the grid with a voltage above 1 kV for the next five years[44].

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[40] Barriers to the development of renewable energy sources, Department of Economy
State Treasury and Privatization

[41] Photovoltaics market in Poland, Institute of Renewable Energy, Warsaw 2024

[42] Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions energy roadmap 2050, european commission, 2011

[43,25] Photovoltaics market in Poland, Institute of Renewable Energy, Warsaw 2024

The second challenge regarding costs is the impact of intermittent energy generation on wholesale market prices. Electricity generated from wind or solar energy has low or zero marginal costs and as its price in the market increases, it can remain at a low level for a prolonged period. This raises concerns about price instability for investors and their ability to recoup capital and fixed operating costs. Therefore, ensuring market mechanisms that provide cost-effective solutions will become increasingly important.

- *Solar Power Plants*

Energy obtained through solar radiation is one of the most common solutions in Poland (18,095 MW); however, this type of renewable energy presents certain challenges. Primarily, the main issue concerns the amount of energy produced depending on the season—there is significantly less energy produced in winter, while the demand is higher. Solar cells also do not produce energy at night, and the materials they are made of, such as cadmium, tellurium, selenium, and arsenic, make more questions regarding to their environmental impact. However, it should be noted that this technology is still in the development phase, and recently, new generations of solar cells have been emerging. Other challenges include: large solar installations occupying a considerable amount of space, as well as the high costs of solar collectors and PV panels, which can be addressed through emerging funding opportunities[45].

- *Wind Farms*

Energy generated using wind farms is the second most popular solution in Poland, with a total capacity of 9,485 MW. The main limitations include changes in the minimum distance requirement from buildings, which has been reduced from 700 to 500 meters, significantly complicating the expansion of residential areas and the process of obtaining special construction permits. However, this change also releases an additional 47% of the potential for onshore wind farms. Other issues include high construction costs for the farms, unstable energy generation dependent on weather conditions requiring energy storage, the loud operation of turbine blades, and light reflections, which can not only disturb residents but also pose a threat to wildlife[46].

- *Hydropower Plants*

Hydropower plants have been known for a long time and have experienced development since the invention of the water turbine. In the case of this type of renewable energy, it is worth noting that this solution does not cause the emission of harmful dust and gases, and also – which is very convenient – there is the possibility of building small hydropower plants, with the reservoirs created being usable during floods and for supplying cities. However, like all renewable energy sources, this technology has its drawbacks, and some of the most significant include: the occupation of agricultural and forested areas for the construction of plants, the need for appropriate development of road and rail connections, changes in the ecosystem around the power plant itself, and increased bottom erosion, which causes a drop in the riverbed and groundwater levels. Another challenge is also the so-called backflow of water, which leads to

[45-30] Michał Hodana, Grzegorz Holtzer, Kinga Kalandyk, Agnieszka Szymańska, Bogdan Szymański, Sylwia Żymankowska-Kumon, „Odnawialne źródła energii" Poradnik, Stowarzyszenie na rzecz efektywności energetycznej i rozwoju odnawialnych źródeł energii „Helios", 2012, https://www.energetyka-polska.pl/geotermia-w-polsce-wykorzystanie-ciepla-ziemi-do-produkcji-energii/

siltation of the riverbed and accumulation of pollutants, necessitating the use of additional filtering devices[47].

- *Geothermal energy*

Another example is geothermal power plants, which, as stable sources of heat, also face certain challenges despite their low operational costs. While the operational costs may be low, the investment expenses are high due to the drilling operations, which also contribute to the disruption of the earth's layers, and the geothermal waters themselves exhibit corrosive properties[48]. The strength of geothermal energy in Poland is primarily based on the availability of geothermal reservoirs. However, despite its significant development potential (especially in the Carpathian region), it is not a widely popular solution in Poland at this time[49].

- *Power plants using biogas and biomass*

Biogas plants are becoming an increasingly popular solution due to the potential for utilizing organic waste, as well as having a zero carbon dioxide emission balance. However, the drawbacks of this solution include the formation of nitrogen oxides during the combustion of biomass itself, as well as the release of carcinogenic compounds into the atmosphere, as biomass can be contaminated with pesticides. The reduction of biodiversity and low calorific value due to the moisture content of the substrate are also problems that need to be addressed[50].

- *Energy Storage*

Another issue is the possibility of temporary outages in the supply of electricity to the system, or oversupply, which in turn requires well-developed energy storage technology to utilize this energy at any given time, such as during increased demand or variable weather conditions and seasons. However, the challenge in this case is the insufficiently rapid development of the large-scale energy storage market which directly limits the development of renewable energy sources (RES) in Poland, as the energy generated in this way needs to be stored somehow. Therefore, having flexible resources, such as the ability to store energy as the share of intermittent electricity generation from RES increases, is a necessity[51].

The question of safety also arises, as the goal of renewable energy sources (RES) is to ensure continuous supply. However, without energy storage, it is difficult to talk about energy stability in the coming years[52].

Summary

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[50] Michał Hodana, Grzegorz Holtzer, Kinga Kalandyk, Agnieszka Szymańska, Bogdan Szymański, Sylwia Żymankowska-Kumon, „Odnawialne źródła energii" Poradnik, Stowarzyszenie na rzecz efektywności energetycznej i rozwoju odnawialnych źródeł energii „Helios", 2012

[51] Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions energy roadmap 2050, european commission, 2011

[52] Agata Surówka. "Problemy i wyzwania prognozowania produkcji energii elektrycznej z OZE w Polsce w kontekście współczesnych kryzysów". Nierówności Społeczne a Wzrost Gospodarczy, 73:134-151. https://www.ceeol.com/search/article-detail?id=1176288

[34] Dorota Micek, Społeczno-kulturowe uwarunkowania rozwoju energetyki rozproszonej w Polsce

The limitations regarding the implementation of renewable energy sources are extremely significant from the perspective of moving towards a low-emission economy. However, attention must be drawn to the enormous potential generated by their use. In the coming years, further technologies and scientific research will address the aforementioned issues, but it is also important to mention the social aspect of the upcoming changes. The increasing social awareness related to the smog problem, reinforced by media coverage and campaigns of local initiatives such as anti-smog alarms, presents an opportunity for the development of renewable energy sources. In this case, however, the challenge is much greater due to the ongoing policy of combating coal rather than presenting renewable energy sources in a favourable light and highlighting the benefits that stem from such solutions. Another important factor is the role of local governments in supporting investment processes in renewable energy, which can contribute to a more enthusiastic acceptance of the upcoming changes. An essential aspect is also education and media messaging about renewable energy sources and the direct associated concern for the environment, which serves as an impetus for engaging in the development of distributed energy, thereby alleviating the problem of energy poverty[53].

INVESTMENT FUNDING - SUPPORT INSTRUMENTS

Poland, like many countries in the European Union, has embarked on an ambitious journey to transform its energy sector, moving away from its traditional reliance on coal towards a more sustainable and diversified energy mix. To facilitate this shift, Poland has implemented a comprehensive suite of financial mechanisms designed to stimulate investments in renewable energy sources across various scales and sectors. This framework comprises a diverse array of instruments, including but not limited to: competitive auction systems for large-scale renewable energy projects, bespoke support schemes for emergent technologies such as offshore wind power, and targeted initiatives to promote the adoption of clean energy solutions at the residential and small enterprise level.

Financial mechanisms supporting large-scale renewable energy installations and plants

- *Renewable Energy Auctions*[54]

The Auction System is central to Poland's support for large-scale renewable energy sources (RES) projects. Introduced by the Renewable Energy Sources Act of 2015, it replaced the green certificate scheme, marking a significant shift in Poland's renewable energy strategy. The system aims to increase renewable energy's share in Poland's energy mix cost-effectively. It operates on a competitive bidding principle, where developers compete for long-term electricity generation contracts. The Energy Regulatory Office (URE) organizes these annual auctions.

Auctions are divided into baskets based on technology type and generation capacity, supporting various renewable energy sectors without direct competition between different technologies. Categories include onshore wind and solar photovoltaic projects above 1 MW, and other RES technologies like biomass, biogas, and small hydropower. Participants submit bids specifying the electricity volume they will generate and the price they will sell it for over 15 years. The auction follows a pay-as-bid model, encouraging competitive bidding while ensuring project viability. Bids are ranked from lowest to highest price, and projects are selected until the auction volume is filled

[54] URE (Energy Regulatory Office). (2023). "Aukcje OZE." https://www.ure.gov.pl/pl/oze/aukcje-oze

or the budget is exhausted, prioritizing cost-effective projects. Successful bidders receive a Contract for Difference (CfD), guaranteeing the bid price for 15 years. This provides a stable revenue stream, reducing investment risk and facilitating financing. If the market price falls below the guaranteed price, the difference is paid to the generator; if it exceeds, the generator pays back the difference.

The Auction System has driven the development of onshore wind and large-scale solar PV projects, significantly increasing Poland's renewable energy capacity and helping meet climate and energy targets. Auction results have shown increasingly competitive prices, reflecting the system's success in driving down costs. The Auction System is set to be phased out for new projects after 2027, in line with EU state aid rules, prompting discussions on future renewable energy support in Poland.

The Energy Regulatory Office has released the schedule for renewable energy auctions planned for 2024. Seven auctions will be held between December 9 and 17, exclusively for new installations.

1) December 9: Auction for biogas installations up to 0.5 MW, biomass combustion, waste-to-energy, and hybrid systems up to 50 MW. Total: 1.11 TWh, PLN 0.609 billion.
2) December 10: Auction for biogas installations over 0.5 MW and waste-to-energy, biomass combustion, and hybrid systems over 50 MW. Total: 1.687 TWh, PLN 0.927 billion.
3) December 11: Auction for agricultural biogas plants with and without CHP over 1 MW. Total: 5.775 TWh, PLN 3.87 billion.
4) December 12: Auction for hydroelectric plants and installations generating energy from biofuels or geothermal sources up to 1 MW. Total: 0.975 TWh, PLN 0.508 billion.
5) December 13: Auction for installations in the same technologies but over 1 MW. Total: 2.04 TWh, PLN 1.038 billion.
6) December 16: Auction for wind and photovoltaic installations up to 1 MW. Total: 11.25 TWh, PLN 3.825 billion.
7) December 17: Largest auction for wind and photovoltaic installations over 1 MW. Total: 21.75 TWh, PLN 6.225 billion.

- *Contract for Difference (CfD) mechanism for offshore wind in Poland*[55]

The Contract for Difference (CfD) mechanism for offshore wind in Poland, introduced by the Offshore Wind Act of 2021, aims to develop the country's offshore wind potential in the Baltic Sea. This support scheme provides long-term revenue stability for projects, reducing investment risks and facilitating rapid scaling in Poland's energy mix.

The CfD is a two-phase system. The first phase (2021-2023) focused on quickly starting projects, allocating up to 5.9 GW of capacity through administrative decisions by the Energy Regulatory Office. This phase supports early projects to build supply chains, port infrastructure, and domestic expertise. Projects are awarded a strike price set by governmental decree, which was PLN 319.6 per megawatt-hour (€71/MWh) in 2021. The second phase, starting in 2025, will transition to a competitive auction system to drive cost reductions as the sector matures.

[55] https://www.gov.pl/web/morska-energetyka-wiatrowa/system-wsparcia

Successful projects in both phases receive a 25-year CfD, longer than the typical 15-year period for onshore renewables, reflecting higher capital costs and longer development timelines.

The CfD guarantees generators a fixed price for electricity. If the market price is below the strike price, the generator receives a top-up payment; if it exceeds the strike price, the generator pays back the excess. This mechanism protects consumers from high prices while providing revenue certainty for developers. Poland's scheme emphasizes building a local supply chain, with targets for local content rising from 20% in the first phase to 45% by 2030. These targets, tied to incentives, aim to develop Poland's offshore wind industry beyond energy production. As of 2023, major projects like Baltic Power (1.2 GW), Bałtyk II and III (1.44 GW combined), and Baltic II (350 MW) have received support, representing significant infrastructure investments in Poland's energy transition.

The auctions are planned for the years 2025, 2027, 2029, and 2031, where installations with a combined capacity of up to 12 GW will be granted the right to cover negative balances. Future auctions will be held based on the development progress of the farms. The Energy Regulatory Office has created a guide for producers with detailed instructions and guidelines on how to apply for public aid, available on the URE website. The auction dates for the first period have been predetermined, along with the maximum total installed capacity for offshore wind farms. The auctions will be held in the following years:

- 2025: maximum capacity of 4 GW,
- 2027: maximum capacity of 4 GW,
- 2029: maximum capacity of 2 GW,
- 2031: maximum capacity of 2 GW.

If in 2031 the winning bids do not use up the offered capacity, an auction for the remaining capacity will be held in 2032, provided it is at least 500 MW.

- *EU Renewable Energy Financing Mechanism (RENEWFM)*[56]

The EU Renewable Energy Financing Mechanism (RENEWFM) is a financial instrument designed to support the development of renewable energy projects across the European Union. Its primary objectives are to facilitate cross-border cooperation, support EU renewable energy targets, and encourage investment in renewable energy. The mechanism operates by linking contributing countries, which provide financial resources, with hosting countries, which agree to have renewable energy projects developed on their territory. This arrangement promotes the efficient allocation of resources and maximizes the renewable energy potential across the EU. Hosting countries, on the other hand, benefit from the investments and the development of local renewable energy infrastructure. The European Commission plays a crucial role in facilitating the selection of projects based on predefined criteria and conditions, ensuring transparency and efficiency in the allocation of funds.

The financial support provided by RENEWFM covers a wide range of renewable energy technologies, including wind, solar, biomass, and geothermal energy. This support can encompass various stages of project development, from planning to construction and operation.

[56] https://cinea.ec.europa.eu/programmes/eu-renewable-energy-financing-mechanism_en

While specific projects in Poland under RENEWFM have not been publicly identified yet, the mechanism is expected to play a crucial role in supporting Poland's renewable energy ambitions.

- *InvestEU Programme*[57]

The InvestEU Programme is a key financial support mechanism designed to stimulate investment across the European Union, including Poland. The InvestEU Fund provides an EU budget guarantee of €26.2 billion, which helps to mobilize at least €372 billion in additional investments. This guarantee reduces the risk for investors, making it more attractive for them to invest in renewable energy projects. Through partnerships with financial institutions like the European Investment Bank (EIB), InvestEU co-finances large-scale renewable energy projects. For example, the EIB, backed by InvestEU, is financing the construction of one of the world's largest offshore wind farms in the Baltic Sea, with a loan of up to €610 million. This project will significantly boost Poland's renewable energy capacity. One notable project supported by InvestEU in Poland is the Baltic Power offshore wind farm. This project, which will be one of the largest in the world, is expected to generate around 4,200 GWh of clean energy annually once completed in 2026. The EIB is providing significant financing for this project, backed by the InvestEU programme.

The Polish government, in collaboration with the European Union, has allocated substantial funds to support the development of RES projects. The support available through Poland's Energy Transition Package is substantial, reflecting the country's commitment to transforming its energy sector. The total budget for the program is around PLN 1 billion (approximately €217 million), which is supported by the EU's Modernisation Fund. This funding is aimed at facilitating the shift from coal to renewable energy sources, ensuring a just transition for affected communities, and modernizing the energy infrastructure. The financial support includes various forms of assistance such as grants, low-interest loans, and subsidies. These funds are intended to cover a wide range of projects, from large-scale wind and solar farms to smaller community-based renewable energy initiatives. Additionally, there are specific incentives for innovative technologies and energy storage solutions, which are crucial for integrating renewable energy into the grid.

In 2019, the EIB Group committed to supporting €1 trillion of investments in climate action and environmental sustainability from 2021 to 2030. Additionally, the EIB aims to gradually increase the share of its financing dedicated to these areas, with a goal of exceeding 50% of its operations by 2025. Furthermore, the EIB Group pledged to align all its financing activities with the principles and goals of the Paris Agreement by the end of 2020.

- *Ścieżka Smart FENG Program with model "Zazielenianie przedsiębiorstw (Greening Enterprises)"*[58]

The "Ścieżka Smart FENG" program, specifically the Zazielenianie przedsiębiorstw (Greening Enterprises) module, is a Polish government initiative designed to help businesses transition toward more sustainable and environmentally friendly operations. It is part of the broader Fundusze Europejskie dla Nowoczesnej Gospodarki (FENG), a program aimed at modernizing Poland's economy through innovation, digitization, and environmental responsibility.

The Zazielenianie przedsiębiorstw module focuses on supporting companies in reducing their environmental impact by adopting green technologies and practices. The goal is to encourage

[57] https://investeu.europa.eu/investeu-programme_en

[58]https://www.gov.pl/web/ncbr/sciezka-smart-nabor-feng0101-ip01-00124, https://www.parp.gov.pl/component/grants/grants/sciezka-smart

enterprises to align with the European Union's Green Deal objectives, which include reducing carbon emissions, increasing energy efficiency, and promoting circular economy principles. The module emphasizes sustainability across different aspects of business operations, including energy use, waste management, and the overall reduction of environmental footprints.

Financial support in the Zazielenianie przedsiębiorstw module is aimed at helping businesses implement green innovations and technologies. This includes projects related to renewable energy installations, energy efficiency improvements, eco-friendly manufacturing processes, and technologies that reduce resource consumption or waste generation. The program provides grants to cover a portion of the costs associated with these green projects, allowing companies to invest in the infrastructure and technologies needed to become more sustainable.

The size of subsidies varies depending on the scale of the project and the specific needs of the enterprise. Typically, the program covers a significant portion of eligible costs, including technology acquisition, equipment upgrades, and the implementation of sustainable business practices. Eligibility for the Zazielenianie przedsiębiorstw module extends to small, medium, and large enterprises that are committed to reducing their environmental impact and improving their sustainability. Projects that demonstrate significant potential for innovation and long-term environmental benefits are particularly encouraged.

Financial mechanisms supporting small-scale renewable energy installations

- *"Mój Prąd" (My Electricity) Program*[59]

The "Mój Prąd" (My Electricity) program, launched in 2019, is a key initiative by the Polish government to promote renewable energy at the household level. It provides financial support for installing small-scale photovoltaic (PV) systems, making solar energy more accessible and affordable. The program aims to increase the number of prosumers in Poland, addressing the high upfront costs of PV installations by offering grants to homeowners. Over the years, "Mój Prąd" has evolved to meet market needs and policy objectives. Initially focused on PV installations, the program's scope expanded to include energy storage, heat pumps, energy management systems, and electric vehicle charging points. The fifth edition, launched in 2023, offers comprehensive support, with grants up to PLN 58,000 (€13,000) for a full system and PLN 6,000 for standalone PV installations.

The program has significantly impacted Poland's energy landscape, supporting over 400,000 household PV installations by 2023. This growth has increased the share of renewable energy in Poland's energy mix and empowered citizens to participate in the energy transition. Key factors in its success include a straightforward application process, direct financial benefits, long-term savings, and environmental impact. Future iterations may focus on integrating residential PV with energy storage, demand response technologies, and smart grid solutions, aligning with broader trends towards a flexible and resilient energy system. The program demonstrates how targeted financial support can drive significant changes in a country's energy landscape, empowering homeowners to contribute to sustainable development.

- *"Czyste Powietrze" (Clean Air) Program*[60]

The "Czyste Powietrze" (Clean Air) program, launched by the Polish government in 2018, is a comprehensive initiative aimed at addressing air pollution and improving energy efficiency in the

[59] https://mojprad.gov.pl/
[60] https://czystepowietrze.gov.pl/

residential sector. With a budget of PLN 103 billion (€23 billion) allocated until 2029, it is one of Poland's most ambitious environmental schemes. The program targets two main challenges: poor air quality during winter months due to outdated heating systems and high energy consumption in aging homes. It provides financial support for replacing old heating sources and improving thermal insulation in single-family homes.

The program covers a range of interventions, including replacing old coal boilers with cleaner heating systems, installing renewable energy technologies like heat pumps and solar thermal collectors, thermal modernization (insulating walls, roofs, and foundations), and replacing old windows and doors with energy-efficient alternatives. A key feature is its sliding scale of support based on household income, ensuring accessibility for a wide range of citizens. The maximum grant amount has increased over time, reaching up to PLN 135,000 (€30,000) for comprehensive renovations. "Czyste Powietrze" supports various heating technologies, favoring low-emission and renewable solutions such as air-source and ground-source heat pumps, gas condensing boilers, biomass boilers, district heating connections, and, in specific cases, electric heating. In addition to grants, the program offers preferential loans to help homeowners finance remaining renovation costs, aiming to remove financial barriers to home energy improvements. As of 2023, "Czyste Powietrze" has benefited hundreds of thousands of households, leading to measurable improvements in local air quality and stimulating the market for energy-efficient technologies and services.

- *Bank Gospodarstwa Krajowego (BGK) Ecological Loan („Kredyt ekologiczny") Program*[61]

The Bank Gospodarstwa Krajowego (BGK) Ecological Loan program is a crucial financial tool designed to aid small and medium-sized enterprises (SMEs) in Poland in transitioning to more environmentally friendly operations. The Ecological Loan program addresses a significant market gap: while large corporations often have access to various green financing options, SMEs frequently struggle to secure funding for environmental investments. One of the key strengths of the program is its flexibility. It can be used to finance both tangible assets (such as equipment and infrastructure) and intangible assets (like patents or licenses for environmental technologies). This comprehensive approach allows SMEs to implement holistic environmental strategies rather than just focusing on isolated improvements.

The program operates through a system of loan guarantees, with BGK providing guarantees of up to 80% of the loan value for eligible ecological projects, with a maximum guarantee amount of €2.5 million. This structure significantly reduces the risk for commercial banks lending to SMEs for green investments, thereby improving access to finance and potentially lowering interest rates for borrowers. The scope of projects eligible under the Ecological Loan program is broad, reflecting the diverse ways in which businesses can contribute to environmental protection and resource efficiency. Eligible investments include the installation of renewable energy sources (such as solar PV, wind, and biomass), energy efficiency improvements in buildings and production processes, implementation of circular economy solutions, water-saving and wastewater treatment technologies, air pollution reduction measures, and the purchase of electric vehicles and charging infrastructure. The application process for the program is designed to be straightforward, with BGK working in partnership with commercial banks. SMEs apply for loans through their usual banking channels, and if the project meets the ecological criteria, BGK

[61] https://www.bgk.pl/produkty/kredyt-ekologiczny/

provides the guarantee. This structure leverages existing banking relationships and infrastructure, making the program more accessible and efficient.

- *“Agroenergia” program*[62]

The "Agroenergia" program is a Polish government initiative aimed at promoting the use of renewable energy in agriculture. It is designed to support farmers and rural communities in reducing their reliance on conventional energy sources, thereby contributing to environmental sustainability and energy independence. The program encourages the installation of renewable energy systems, such as solar panels, wind turbines, and biomass installations, in agricultural settings.

The program is administered by the National Fund for Environmental Protection and Water Management (NFOŚiGW) in Poland, and it targets both individual farmers and agricultural enterprises. Agroenergia provides financial support in the form of grants and low-interest loans to cover part of the costs associated with the purchase, installation, and operation of these energy systems. The initiative also aims to increase energy efficiency in rural areas by funding projects related to modernizing heating systems and improving overall energy management in agricultural *businesses*.

- *"Energia dla Wsi" (Energy for Villages)*[63]

"Energia dla Wsi" (Energy for Villages) is a Polish government initiative aimed at promoting the development of renewable energy sources in rural areas, with a focus on enhancing energy independence and sustainability for agricultural communities and businesses. One of the program's key goals is to support the development of RES by funding photovoltaic (solar) systems, small-scale wind farms, and biogas plants, as well as energy storage installations, which are critical for improving energy reliability.

In terms of funding, "Energia dla Wsi" offers substantial financial support through a combination of grants and low-interest loans. For photovoltaic and wind energy projects, grants cover up to 50% of eligible costs, with a maximum grant of up to 15 million PLN per project. Loans can be obtained to cover up to 100% of the remaining costs, often with favorable interest rates, and there is a possibility of loan forgiveness of up to 50% in certain cases. For biogas and biomass installations, grants similarly cover up to 50% of eligible costs, with a cap of 20 million PLN per project. Loans, again, can cover the remaining project costs, with potential loan forgiveness of up to 40%. Additionally, energy storage systems, which enhance the efficiency of renewable energy installations, are eligible for grants up to 20% of project costs, capped at 2 million PLN.

The program is available to farmers, agricultural cooperatives, and businesses involved in agricultural or agri-food production in rural areas. Projects that combine multiple renewable energy technologies, such as solar panels with energy storage, or have the capacity to generate surplus energy for sale to the grid, are particularly encouraged. "Energia dla Wsi" is administered by the National Fund for Environmental Protection and Water Management (NFOŚiGW), which reviews applications based on their potential to generate renewable energy, improve energy efficiency, and contribute to environmental sustainability.

The described financial mechanisms form a comprehensive strategy aimed at accelerating Poland's energy transition, improving energy security, reducing environmental impact, and

[62] https://www.gov.pl/web/nfosigw/agroenergia-2021
[63] https://energiadlawsi.pl/

fostering innovation in the clean energy sector. This analysis will delve into the details of each major program, examining their objectives, implementation, impacts, and future outlook, providing a thorough understanding of Poland's approach to financing its renewable energy future. Each of these mechanisms is tailored to address specific challenges and opportunities within different segments of the renewable energy market.

RES DEVELOLMENT SCENARIOS

In the long term perspective, improving energy security can be achieved by reducing emissions in the energy sector, diversifying the energy generation structure and reducing the intensity of fossil fuel use. Although the development of most RES technologies still requires support and affects the increase in the costs of operating the energy system, the use of RES will affect the decrease in wholesale energy prices, as well as the reduction of costs related to pollution emissions, such as fees for a unit of energy produced and environmental and health costs. This will affect the increase in the competitiveness of the economy in the long term perspective.

The increase in the share of RES in gross final energy consumption is one of the three priority areas of the EU's climate and energy policy, as well as global policies and actions to combat climate change. The strategic project for Poland in the coming years in this area is the development of offshore wind energy and distributed energy. In 2021, Poland declared that as part of its participation in the implementation of the EU-wide target for 2030, it would achieve a 23% share of RES in gross final energy consumption in 2030 (measured as total energy consumption in power generation, heating and cooling, as well as for transport purposes), taking into account the national potential of renewable resources, the competitiveness of RES technologies, and the technical possibilities of their operation in the National Power System. At that time, it was estimated that by 2040 the share of renewable energy would be at least 28.5%. In 2024, the Ministry of Climate and Environment began updating this document.

Taking into account the above and the current trend of changes, two scenarios of transformation towards a zero-emission economy have been outlined: real and ambitious. Due to the rising costs of emissions, the need to maintain energy independence and social acceptance of pro-environmental changes, the pessimistic scenario, characterized by dependence on fossil fuels, has not been analyzed. Both scenarios presented below assume significant development of renewable energy sources. The forecasts assume that the total production of electricity in Poland is to amount to about 200 TWh/year, i.e. it should be about 3 times higher than at present. It is true that increasing energy efficiency in Poland reduces the demand for energy per unit of gross domestic production. Nevertheless, it is predicted that by 2040, electricity consumption in Poland will increase rapidly as a result of the electrification of transport, heating, industrial production and the development of electrolyzers. Thus, GHG emissions will be reduced by approximately 84% compared to the 2005 reference level. The analysis was based mainly on the proposed targets of the updated National Energy and Climate Plan (2021-2030) [64], which assumes that:

- in 2030, 56% of energy in the power industry will be produced from renewable energy sources,
- 32.1% of the electricity demand in the heating and cooling sector will be covered by generation from renewable energy sources,
- the share of renewable energy sources in transport will be 17.7% (Fig. 5).

[64] https://www.gov.pl/web/klimat/national-energy-and-climate-plan-for-the-years-2021-2030

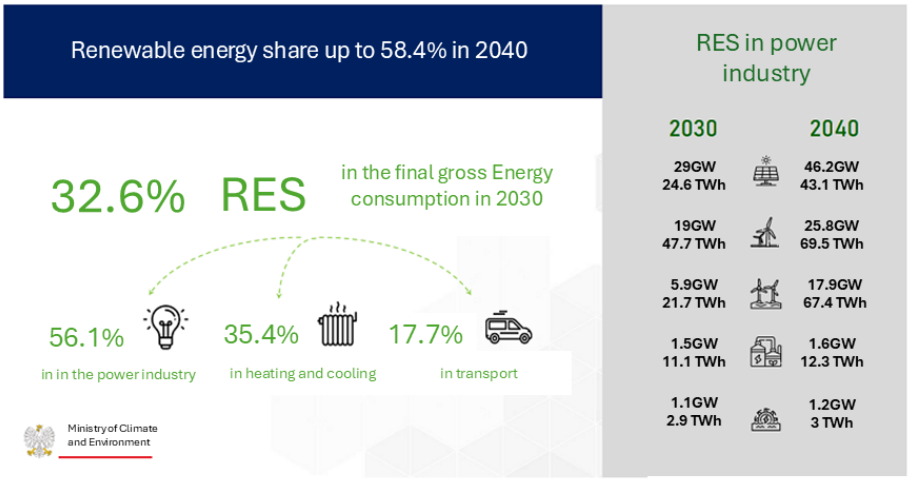

Figure 5. The forecast of energy share for Poland in 2040 [65]

In both scenarios, electricity production in Poland will increasingly rely on energy generated from renewable sources dependent on weather conditions, which means that:

- energy sector faces periods of oversupply, especially in summer, and deficits in electricity production in winter seasons,
- basing the mix on renewable sources, emphasizes the need to develop storage, cross-border connections, demand-side management (DSR) in order to increase the flexibility of the system and its ability to balance demand and supply.

In the latest assumptions National Energy and Climate Plan (NECP) [66] it was assumed that in 2030 the installed capacity in generating units in the Polish energy sector will amount to 93 GW or 96 GW – depending on the scenario (Fig. 3). The Ministry of Climate wants to enter two scenarios into the NECP – WEM (a scenario of transformation in market and technical conditions – referred to as actual) and WAM (a scenario of ambitious transformation – referred to as ambitious).

In the actual scenario, the installed power plant capacity in Poland in 2030 will increase to 93 GW, with renewable energy sources dominating (58%), and mainly coal (23%), as well as natural gas and hydrogen (13%). Energy storage, DSR and pumped-storage power plants are to provide smaller capacities to the national power system. In this scenario, renewable energy sources are to provide 50% of energy, coal-fired power plants – 30%, and gas and hydrogen power plants – 16%.

In the ambitious scenario, the installed generating capacity of domestic power plants is expected to be 96 GW, with a 59% share of renewable energy, a 21% share of coal-fired power plants and a 12% share of sources based on natural gas and hydrogen. This scenario assumes a larger share of renewable energy in the generating mix (56%). In turn, the share of coal-fired power plants is to reach 22%, and gas and hydrogen power plants – 16%.

In summary, the growing electrification of economy sectors will drive Poland's economic development. The industry and energy sector have the greatest impact on the environment and economy. Their transformation towards zero-emission generation will require the development of

[65] Ministry of Climate and Environment
[66] https://www.gov.pl/web/klimat/prekonsultacje-w-zakresie-aktualizacji-dokumentow-strategicznych-kpeikpep2040-

short-term energy storage, i.e. batteries, and long-term storage, i.e. hydrogen from electrolysers. To areas most dependent on cheap and low-emission energy include: electric vehicles, heat pumps, air conditioning, electrolysers and industry. Due to the technical limitations of the current transmission infrastructure and the technical possibilities of building new RES installations, the development of local energy islands with local production of green hydrogen is highly probable.

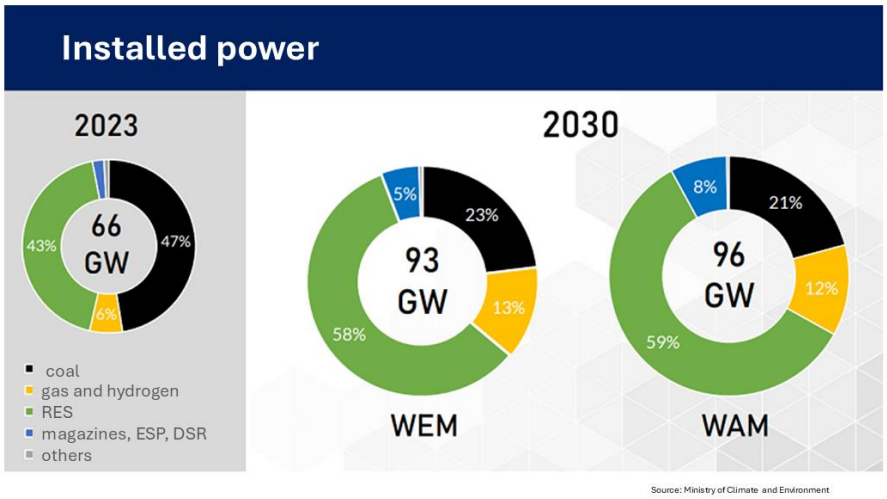

Figure 6. The energy forecast for Poland in 2030

SOCIAL ACCEPTANCE

Like other European countries Poland has undergone a rapid process of education and raising awareness about the need to build energy independence based on alternative energy sources, driven by Russia's attack on Ukraine. Security, independence, and economic factors have become priorities, pushing environmental concerns to the background. To sustain this trend, social acceptance of renewable energy is necessary. This is a crucial factor, which must, however, be supported by knowledge about the benefits of energy transition.

- *Why is Poland particularly vulnerable to socio-climatic tensions?*
  - Despite its fast pace of development, the Polish economy remains energy-intensive. Energy-intensive industries, such as heavy industry and manufacturing, still play a significant role in Poland’s GDP and employment.
  - Coal continues to provide about two-thirds of Poland's electricity and heat. Decarbonization is a relatively new area of government policy, and social agreements on the closure of hard coal and lignite mines have only been reached in recent years. High energy prices may pose challenges to both industry and households, complicating the coal phase-out process.
  - The housing sector in Poland is heavily reliant on coal. The increasing number of energy-poor individuals, i.e., those struggling to cover energy costs, is also becoming an issue. Without adequate support mechanisms, the energy transition may exacerbate social inequalities.
  - Poles have a transactional approach to climate policies. While they generally support them, they are skeptical of new environmental taxes. This skepticism likely arises from some issues with trust to the state institutions and the reluctance of some parts of society to believe in the negative effects of climate

change. Poles would be more inclined to place the burden of reducing energy consumption on the wealthiest social groups, which is reflecting a varied approach to environmental responsibility.

- The implementation of a new carbon tax without proper protective mechanisms could lead to further polarization in a society. Conflicts may intensify if climate reforms are perceived as being enforced without sufficient support for the most vulnerable groups.

- *Coal and Miners*

The energy transition in Poland presents a unique challenge, more complex than in many other European Union countries, primarily due to the historical and cultural significance of coal as the main energy source.

For years, coal was the understructure of Polish industry and a source of stable jobs, especially in mining regions like Silesia. Therefore, older generations, whose lives were built around the coal industry, often resist alternative energy sources. Additionally, the lack of environmental education leads to issues related to climate protection and the necessity of moving away from coal being often misunderstood or downplayed. For example, anti-smog campaigns, which focus on visible effects of air pollution like smog, have been effective in raising awareness. However, less visible issues like CO_2 emissions are not as well understood. Moreover, beliefs in the cost-competitiveness of traditional energy sources, such as coal, hinder investments in renewable energy sources. Government subsidies that offset the rising costs of coal in 2022 further reduced the motivation to invest in modern energy technologies.

For Poland's energy transition to be successful, it must be conducted fairly, taking into account the needs and concerns of the regions most affected by the changes. Particularly important is the support for mining regions through development and training programs that will enable miners to acquire qualifications in new sectors, such as wind energy.

- *Prosumers and Renewable Energy Farms*

To gain social acceptance for investments in renewable energy in Poland, it is crucial to demonstrate the economic benefits these ventures can bring, both to individual energy consumers and local communities. Prosumers - those who not only consume energy, but also, produce it - play an important role here.

Launching of the net-billing system was a step aimed at increasing individual energy consumers' involvement in renewable energy production. Through this system, prosumers can sell surplus energy produced back to the grid and later buy energy when needed at current market prices. In the Polish context, photovoltaic panels are particularly popular. An increasing number of households are choosing to install them, driven by the availability of subsidies and potential savings on energy bills.

The construction of larger renewable energy plants, especially wind farms, often requires the approval of local communities. In Poland, these issues are particularly complex due to the so-called Wind Turbine Act, which introduced restrictions on the location of wind farms in relation to residential buildings. The 10H rule, giving local communities the right to decide on wind farm locations, was intended to increase social acceptance by ensuring that investments are made with respect for residents' interests. The law also aimed to ensure that wind farms would be safe and would use modern technologies that minimize environmental impact. Unfortunately, further

amendments to this law, which were initiated too hastily, contributed to increased uncertainty and reduced trust in both the government and the very concept of wind farms. Frequent changes in regulations regarding wind farm locations have complicated investment planning and negatively impacted the perception of such projects by local communities.

- *The Wind Farm Scandal and NIMBY*

The development of wind farms in Poland plays a key role not only in achieving climate goals but also in ensuring the country's energy security. The May 2021 incident, when a failure in a large conventional power plant threatened to destabilize the entire system, demonstrated the risks of relying solely on large, centralized production units. In contrast, distributed renewable sources, particularly wind farms, offer greater flexibility and resilience to such threats. The sudden rise in energy prices and the need to reduce dependence on Russian energy resources have made renewable energy sources, especially onshore wind energy, viewed as strategically important.

Although legal changes related to the 10H law negatively impacted the wind industry's development, they sparked social dialogue and interest in the issue on an unprecedented scale. The 10H law, which restricted the construction of wind farms near residential buildings, caused numerous controversies and problems but also initiated a broader public debate on the benefits and challenges of wind energy.

In the past, the lack of acceptance for such investments often resulted from a deficit of dialogue and transparency. Therefore, it is crucial for investors and local authorities to engage in open discussions with residents, informing them about the benefits of renewable energy and minimizing any potential negative impacts. The NIMBY (Not In My Backyard) phenomenon, which refers to opposition to locating projects near one's home, is often driven by concerns about potential health risks, the nuisance of nearby developments, reduced quality of life, or decreased property values. To prevent it, it is necessary to provide education and reliable information about how wind technologies work, their environmental impact, and the benefits of locating such investments in the area.

- *Energy Clusters and Distributed Energy*

In Poland, rising conventional energy prices, enhanced availability of renewable energy technologies, and growing consumer awareness and independence are leading to increasing interest in distributed energy. This approach enables residents and local investors to actively participate in small-scale energy production and distribution, contributing to the sustainable development of local communities.

Distributed energy, also known as 'citizen energy', promotes the development of economically and technologically belated regions. By engaging individuals, organizations, institutions, and companies outside the energy sector in energy production and management, citizen energy can help reduce energy poverty and social exclusion. This is possible through the local production of electricity and heat from renewable sources and the energy modernization of buildings, which allows of energy savings.

Energy clusters are a key element of distributed energy. Their activities not only improve air quality and the health of residents but also their economic situation. Local energy initiatives, such as energy clusters, can create new workplaces, promote local energy independence, and strengthen social bonds. In Poland, there is significant potential in local leaders and enthusiasts who are

committed to developing renewable energy initiatives. Energy cluster leaders, often from local communities, play a major role in creating and growing these initiatives. Their involvement not only motivates others to take action but also helps build positive attitudes among residents.

Further education and experts' support are necessary for distributed energy in Poland to effectively meet users' needs. Currently, many photovoltaic installations are oversized, resulting from a lack of proper economic analysis and often influenced by the recommendations of installers. Therefore, it is crucial to promote appropriate attitudes toward energy and align installation capacity with actual consumer needs. Education on energy management and awareness is crucial, especially given the rise in electricity prices, which will undoubtedly influence the further development of micro-installations.

The transition toward climate neutrality cannot be driven solely from the top-down, through new technology and market mechanisms. The grassroots movement initiated by citizens, who are also part of local communities, is crucial for the transition to be effective and fair. For everyone to enjoy its economic, environmental, and social benefits, it is important not to perceive it as a tool for limiting national freedom and sovereignty by the EU, but rather as an opportunity for growth and strengthening the country's position.

RECOMMENDATIONS

Although energy transformation and decarbonization are becoming a fact in Poland, the exact plan and pace of achieving these goals are still being determined. However, coal definitely will be gradually phased out in the coming years, with a complete phase-out to occur by 2049. Natural gas has the potential to replace coal-fired generation capacity and act as a transition fuel in the next 10-15 years, helping to stabilize renewable energy capacity. On the other hand, natural gas may be exposed to negative demand and supply shocks (e.g., visible in price volatility). External factors such as the price of natural gas, its availability and ETS costs will have a direct impact on the length of this transition period and the attractiveness of gas fuel. Forecasts in this area are subject to significant risk. Biomethane production is partly a remedy in the event of occurring the pessimistic scenario. As a low-emission alternative to natural gas, it may decide on the possibility of maintaining the competitiveness of the Polish economy. However, it requires further development and increasing the scale of production and transition from local to national.

The regulatory and business environment is expected to drive changes in industry, transport and heat production. The energy transformation will certainly require electrification and the development of decarbonized fuels (in particular biomethane and green hydrogen. The forecasts assume that the total production of electricity in Poland is to amount to about 200 TWh/year, i.e. it should be about 3 times higher than at present.

In the ambitious RES development scenario, the installed generating capacity of domestic power plants is expected to be 96 GW, with a 59% share of renewable energy, a 21% share of coal-fired power plants and a 12% share of sources based on natural gas and hydrogen. Further development of renewable energy sources will create new jobs – it is estimated that offshore wind energy alone will provide jobs for 100 thousand people. Further development and investment in renewable energy sources will reduce CO_2 emissions by 102 million tons per year [67].

[67] https://www.teraz-srodowisko.pl/publikacje/energetyka-wiatrowa-w-polsce-2024/teraz-srodowisko-publikacja-energetyka-wiatrowa-w-polsce-2024.pdf

The development of batteries for short-term energy storage and hydrogen from electrolyzers for long-term energy storage will be necessary for the transition to zero-emission power. The industries, heat pumps, air conditioners, electric cars, and electrolyzers are the ones most reliant on inexpensive, low-emission energy. The creation of local energy islands with on-site green hydrogen production is very likely given the technical constraints of the existing transmission infrastructure and the technical viability of constructing new RES installations.

In the case of geothermal, in order to ensure its continued development, it will be crucial to provide stable financing for these investments. A dedicated program seems to be the most appropriate approach. However, the development of geothermal must be accompanied by the strengthening of industry and production capacity. An important role will be played by inter-sector cooperation, which is one of the guarantors of the success of further geothermal development in Poland.