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Poland's Energy Efficiency in Terms of Energy Savings and Sustainable Development

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Abstract:

Purpose: *It is necessary to systematically increase the share of RES (Renewable Energy Sources) in total production to reduce the share of coal-based energy. The article presents a detailed analysis and assessment of the use of RES in Poland, along with recommendations for the future.*
Design/Methodology/Approach: *The article uses a literature review and analysis of the activities carried out in enterprises.*
Findings: *The analysis carried out by the authors indicates that the most rapidly developing forms of RES in Poland are photovoltaics and wind farms.*
Practical Implications: *Reducing CO2 emissions is still a significant challenge for us, one that also imposes enormous costs on the economy. The projected prospects for RES in Poland by 2030, although larger, still do not account for even half of the country's overall energy demand. RES in Poland should therefore be treated as a form of supporting energy production and a possibility to generate savings for both individuals and companies that can invest in RES installations and produce energy for their own needs or sell the excess energy to the grid.*
Originality/Value: *The research results presented in the article present an assessment of the use of renewable energy sources in Poland, along with recommendations for the future.*

Keywords: *Renewable energy source, energy in Poland, environmental protection, reduction of pollution.*

JEL codes: *K32, N7, O1, O13, P18, P28.*

Paper type: *Research article.*

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1. Introduction

Renewable energy sources (RES) are based on natural and, most importantly, inexhaustible resources. RES guarantee, first of all, emission-free production of electric or thermal energy. We distinguish the following resources: wind, hydro, geothermal, solar, and biomass energy (Xie and Li, 2024; Liu, 2024). Each of these types of energy has its own characteristics and can be used appropriately in different geographical areas (website: https://eon.pl/dla-domu/portal-o-odnawialnych-zrodlach-energii/zielona-energia/odnawialne-zrodla-energii).

Wind energy is based on the use of wind energy that drives turbines, where the kinetic energy of the wind is converted into electricity. A turbine mainly consists of three major parts: the tower, the moving nacelle, and the rotor – these are the blades that rotate to generate energy (website: https://eon.pl/dla-domu/portal-o-odnawialnych-zrodlach-energii/zielona-energia/odnawialne-zrodla-energii).

Hydropower harnesses the power of flowing water in various systems of weirs, dams, and turbines, where kinetic energy from water movement is converted and electricity is generated. This category also includes current and tidal energy, where changes in sea and ocean levels are used (website: https://eon.pl/dla-domu/portal-o-odnawialnych-zrodlach-energii/zielona-energia/odnawialne-zrodla-energii).

Geothermal energy is energy that comes from inside the earth. It is the thermal energy of rocks, water, and the ground beneath the earth. Geothermal energy resources are extracted using special wells that resemble oil wells. The share of this energy in Poland is small and located mainly in the Podhale region, which is used mainly for heating purposes. The first heating system was built in the 1990s in Biały Dunajec. Because of the low yields of this form of energy, geothermal water is used mainly for spa purposes, and the dominant countries using ground heat are Iceland and the Philippines (Kępińska, 2018).

Biomass energy. Any substance of plant and animal origin that has undergone a biodegradation process, known as biomass, can be used to produce this type of energy (Henriques, 2024). The following types of biomass can be distinguished: solid (plants, wood), liquid (biofuels such as rapeseed), and gaseous (biogas). Biomass is used primarily to produce thermal energy but has recently been increasingly used to generate electricity (Antar, 2021; Saleem, 2022). It is worth noting that the share of renewable energy in transport fuel is an important target for many countries, as well as an indicator of the share of renewable energy in the EU.

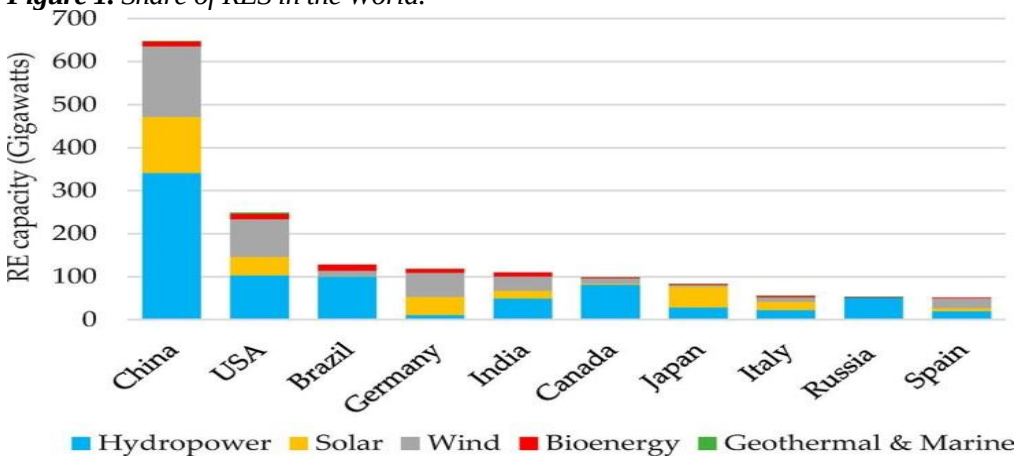
A common target for all EU countries for 2020 was at least a 10% share of renewable energy in transport (Borucka, 2020; Świderski, 2018). Transport emissions account for 20–25% of global carbon dioxide emissions (Borucka, 2021; Kozłowski, 2020). Geothermal energy is energy that comes from inside the earth, and it uses the heat of the water and rocks below the surface. This type of energy is

the most challenging energy source to obtain since the deposits are deep underground. Resources are extracted through wells where hot water or steam is drawn, which is converted into energy at a power plant. The main form of geothermal energy is heat, but electricity production is also possible (Muraoka, 2022; Karayel, 2022). What all of these alternative heat sources have in common is that they do not emit any harmful gases into the atmosphere. Their use does not contribute to the so-called greenhouse effect. They also belong to the so-called "green energy", i.e. they are generally easily accessible and cheap to operate.

2. Literature Review

The analysis of renewable energy sources in the world's largest economies allows for drawing many interesting conclusions regarding energy transformation, climate policy, and the impact on the global economy. As part of such an analysis, it is possible to assess, for example, the development of renewable energy infrastructure, the share of renewable energy in the energy mix, as well as the support policy of a given country, or the impact on the economy and labor market. Regarding the use of RES, China is by far the leader compared to other countries in the world (Figure 1).

Figure 1. *Share of RES in the World.*



Source: *Sharma, et al., 2021.*

This is related to the so-called sustainable development of this country. The main assumptions are (Sharma *et al.*, 2021):

- Preventing climate change,
- Strategic use of natural resources,
- Job growth,
- Sustainable development is development without harming nature. Thus, resources play a key role.

The other key country with a significant RES share is the US. In the United States, about 12% of energy production is based on RES, whereas the share of nuclear

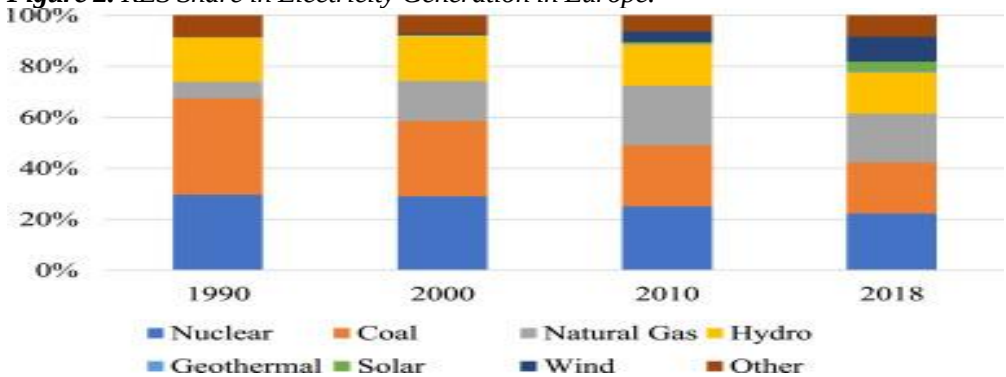
energy amounts to 8.6%. The reported consumption of RES energy in 2019 was three times higher than in 2020. The slow progress of RES in the United States is due to concerns about efficiency and return on investment. In addition, in the U.S., the current market price of renewable fuels is relatively high compared to fossil fuels, further discouraging both companies and individuals from using this form of energy generation (Lahiani, 2021; Shafiullah, 2021).

Regarding RES share in Europe, electricity comes mainly from wind turbines and photovoltaic installations (Xie and Li, 2024; Yang *et al.*, 2024). Electricity consumption is projected to increase significantly in 2050 due to the electrification of road transport. By this year, 550,810 wind turbines and 5,636 km^2 of photovoltaic panels are to be built in Europe. It is estimated that 57% of the electricity demand will be covered by wind turbines and 43% will be produced by photovoltaic panels.

The dominant country in the EU producing renewable energy from photovoltaic installations is Portugal, which claims to be able to achieve a 75% share of photovoltaic installations and wind turbines in electricity production by 2050. For South-Eastern Europe, a share of 28.9% for wind turbines and 22.5% for photovoltaic installations is expected (Lidija, 2021).

In 2009, the European Union enacted the Renewable Energy Directive 2009, which imposed a 20% RES share by 2020. The RES share increased from 12.6% (2009) to 18% (2018). In 2018, 19.7% of thermal energy and 8% of electricity came from alternative sources. Most countries have achieved the stated goal. There are even countries that have exceeded it. These include Sweden, Finland, and Denmark, but also some that are laggards, like France, Spain, and Germany. The differences that arise are due to equipment and infrastructure resources and dissemination of technology. Over the years, the overall share of RES for Europe has been increasing. Solar, wind and geothermal energy production increased significantly, while the share of hydropower was stable over the 2018–2020 period (Guy and Leung, 2021). Figure 2 shows the change and share of each form of RES between 1990 and 2018.

Figure 2. *RES Share in Electricity Generation in Europe.*



Source: *Guy and Leung, 2021.*

3. Research Methodology

In the article, based on available scientific literature and analysis of quantitative materials, a comprehensive assessment of the state and development prospects of renewable energy sources (RES) in Poland was conducted. The study considered current statistical data on energy production from various renewable sources, as well as strategic documents and reports of national and international institutions.

According to Jankowska *et al.* (2021), the insolation in Poland allows to obtain an efficiency of photovoltaic power plants at the level of 1,050–1,100 kWh/m^2. However, forecasts by PSE (the operator of the extra-high voltage grid) estimate that demand in 2035 could reach 32.7 GW. As described in (Jankowska *et al.,* 2021), 376 km^2 of available land would be needed to meet this demand, taking into account a 15% correction for cell efficiency loss. There is 136,030.22 km^2 of arable land available in Poland, which means that it has enough land to be used, even with strict land use assumptions, and that the development of energy storage technologies is possible.

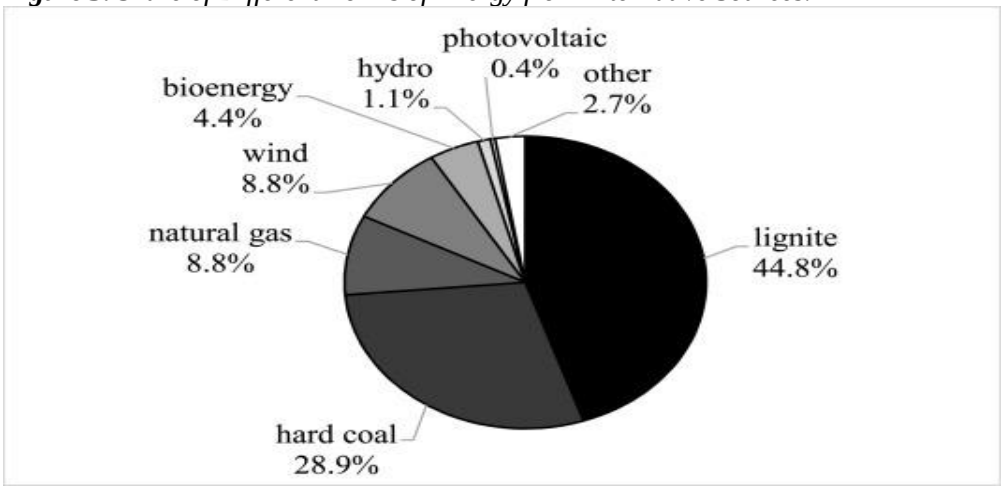
The average minimum wind speed at the turbine level, ensuring the viability of wind farms, is 5m/s (Jankowska et al., 2021). At an altitude of 80 m above sea level, the average annual speed varies between 5–6 m/s over most of the country. In contrast, in the north, this value averages about 7 m/s. In turn, by the Baltic Sea, at an altitude of 120 m above sea level, the average annual wind speed is eight m/s (Jankowska *et al.*, 2021). As included in the calculation (Jankowska *et al.*, 2021), for a winter peak demand of 20,3535.2 GW, the area requirement for this production is 7,040 km2. This is 15.4 times the possible availability of land in Poland, considering the wind speed condition. Therefore, considering protected areas and the development of future energy storage technology, Poland's land resources are not a limitation for the development of wind energy.

According to European Hydropower, the hydropower potential in Poland is 13.8 TWh per year. At present, about 2,000 MW are in use, which constitutes 13-17%. As of 2019, the installed capacity was 974 MW. The value to date remains at a similar level (Jankowska *et al.,* 2021). According to B. Jankowska, A. Staliński, and P. Trąpczyński (Jankowska *et al.,* 2021), the potential of biogas production in Poland ranges from 5 to 18 billion m^3. According to the National Agricultural Support Centre, 1 kW of power corresponds to an average of 4,057 m^3 of biogas production, translating into 1.2–4.4 GW of total domestic potential. In the case of solid biomass, the production potential in Poland is 17.5 billion m^3.

The most commonly used form of biomass is the solid form called pellets. It is a fuel, usually in the form of pellets, used mainly for combustion in individual and collective heating installations. The use of pellets in Poland is steadily increasing but continues to decline in the energy sector. The dominant energy source in Poland is coal. Its share is gradually decreasing, but it still plays a dominant role in the

country. In 2019, the share of electricity from coal was 73.6%, where 44.8% came from lignite and 28.9% from hard coal (Jankowska *et al.*, 2021).

Figure 3. *Share of Different Forms of Energy from Alternative Sources.*



Source: *Jankowska et al., 2021.*

According to Jankowska *et al.* (2021), the most common renewable energy source is wind power, producing 58.1% of electricity. The fastest growth was recorded for photovoltaics, but its share is the smallest. Biomass energy and hydropower have stable production levels.

4. Research Results

a. Wind Energy

As mentioned earlier, wind energy uses the conversion of wind kinetic energy into electricity in a wind turbine. Its main advantages are as follows:

- It is an inexhaustible and completely renewable source of energy,
- Wind energy is completely free,
- It produces a fair amount of power in relation the amount of space it occupies,
- It is non-invasive and does not cause changes in the ecosystem.

Disadvantages, on the other hand, are as follows:

- Power production is only possible at speeds above 7 km/h,
- Large capital costs,
- High terrain requirements,
- It poses a threat to birds,
- It is a source of harmful noise levels

According to the Supreme Chamber of Control (2020, website: (https://www.rynekelektryczny.pl/moc-zainstalowana-oze-w-polsce/), wind power plants have the largest share among renewable energy sources in Poland, currently (as of July 2021) at 46%. The wind energy sector is playing a growing role not only

in Poland but also worldwide. Poland, Brazil, China, and Turkey have the highest growth rates in wind power.

As reported in The Renewables 2020 Global Status Report (Andrzej, 2020), the share of energy from alternative sources at the end of 2019 was 27.3%, with 5.9% being wind energy. In 2018, the share of RES was 26.2%, while of wind energy – 5.5%. Table 1 shows the share of wind energy in 2019.

Table 1. *Share of wind power plant capacity in 2019*

Wind power plant capacity worldwide	Wind power plant capacity in Europe	Wind power plant capacity in Poland
651 GW	205 GW	5.9GW

Source: *Odnawialne źródła energii – co warto wiedzieć? website: https://eon.pl/dla-domu/portal-o-odnawialnych-zrodlach-energii/zielona-energia/odnawialne-zrodla-energii.*

The share of wind plant power capacity continues to grow. In 2018, there was an increase of 50 GW of capacity, and in 2019 the share increased by 60 GW. The fastest-growing countries in this regard were China, the United States, Germany, and Brazil. When it comes to Europe, 15.4 GW of wind capacity was built in 2019, up 27% from 2018. Most new installations were built in Sweden, the United Kingdom, Spain, and Germany. Denmark had the largest share of wind power in 2019 – 48%, followed by Ireland at 33% and Portugal at 27%. Forecasts show that by 2023, wind power generation will increase by 90 GW, reaching 277 GW (website: https://eon.pl/dla-domu/portal-o-odnawialnych-zrodlach-energii/zielona-energia/odnawialne-zrodla-energii)

The current wind capacity in Poland reaches 5.87 GW, which is 68% of the total installed RES capacity in Poland, amounting to 8.58 GW. In 2019, Poland was on track to meet the binding 15% RES target imposed by the EU in total energy consumption by 2020. However, due to a law introduced on 20 May 2016, which set the minimum distance of wind turbines from buildings and protected areas, the 2020 RES targets still need to be achieved.

This was evidenced by the fact that only 50 MW of new wind energy was obtained in 2016 and in 2017 – 10 MW. The amendment to the RES Act, published on 29 June 2018, introduces changes that are expected to positively affect conditions for wind investments. However, the distance criterion still applies (Śliz-Szkliniarz *et al.,* 2019).

The guidelines of the Energy Policy of Poland until the year 2030 recommend the use of various types of renewable energy. With regard to wind energy, the development of this technology is planned both onshore and offshore. It will result in (Igliński *et al.,* 2019):

- An increase in the share of renewable energy by min. 15%,
- Achieving a 10% share of biofuels in the biofuel market.

Figure 4. *Wind Power Plant Installations and Capacity in Poland*

Source: *Igliński et al., 2019.*

Figure 3 shows that wind energy is developing most strongly in the northern regions, i.e., in Zachodniopomorskie (1,200 MW), Pomorskie (470 MW), Kujawsko-Pomorskie (480 MW), and Wielkopolskie (500 MW) Voivodeships (Igliński et al., 2019). The smallest share is in the Świętokrzyskie, Małopolskie, and Lubelskie Voivodeships.

Legal regulations in Poland require that electricity from renewable energy sources be purchased by energy traders.

It should be emphasized that while maintaining the balance between the development of large and small installations, separate energy collection should be planned for facilities with installed capacity up to 1 MW and facilities with installed capacity above 1 MW. Energy generated by installations with a capacity of less than 0.5 MW will be purchased by purchasers, but energy generated by installations with a capacity equal to or greater than 0.5 MW will be sold directly on the market with the condition that at least ¼ of the electricity must be produced by RES installations (Igliński *et al.,* 2019). For the distribution or transmission of electricity, an energy company shall charge a fee for the availability of energy from renewable sources in the national grid. The said act ensures the development of prosumer energy by providing a guaranteed purchase price for renewable energy (Igliński *et al.,* 2019)

4.2. Hydropower

Hydroelectric power plants convert electricity by converting the potential energy of water into mechanical energy in a turbine and then into electricity through generators (Niechciał, 2014). The following types of hydropower power plants can be distinguished:

- Hydroelectric dam power plant – it consists of building high dams where it is possible to dam up water. They are built in areas of artificial reservoirs or lakes. An example of a dam power plant in Poland is the Pilchowice I hydroelectric power plant, with technical data presented in Table 2.

Table 2. *Technical data of the Pilchowice I power plant*

Km of the river	Bóbr 196+700
Height [m]	62
Length at crown [m]	270
Width at the base [m]	50
Width at crown [m]	7.5
Reservoir capacity [million m^3]	50
Reservoir area [ha]	240
Reservoir length [m]	6

Source: *Elektrownia wodna Pilchowice I, Tauron, website: https://www.tauron-ekoenergia.pl/elektrownie/energia-wodna/ew-jelenia-gora/pilchowice-1.*

- Pumped-storage – its important advantage is the ability to produce electricity depending on the demand (e.g., day/night). It has two reservoirs, one located at ground level and the other at elevation. When demand is low, water is pumped to the higher elevation reservoir, but when demand is high, water is released into the lower elevation reservoir, and the water-energy generates electricity.

  An example of such a power plant is the Porąbka-Żar power plant. The lower elevation reservoir is the artificially created Międzybrodzkie Lake. The higher elevation reservoir is located on top of Żar Mountain at an altitude of 761 m above sea level. The shape is similar to an ellipse, where the longer axis is 650 m, and the shorter axis is 250 m. The power plant has a total capacity of 500 MW.

- Run-of-the-river power plants – harness the power of a flowing river. Excellent efficiency can be achieved where there is a natural river gradient. An example of such a power plant is the hydroelectric power plant in Włocławek. It has an installed capacity of 160 MW and has an annual production of 750 GWh per year. It generates 20% of the electricity of all hydroelectric power plants in Poland. The technical data are presented in Table 3.

Table 3. *Technical data of the Włocławek hydroelectric power plant*

Installed power of the hydro system:	26.7 MW
Generator rated voltage:	10.5 KV
Generator rated current:	1.750A
Field current:	1.320A
Rated turbine discharge:	365 m^3/s
Rated head:	8.8 m
Permissible head range:	5.25–12.75m
Block transformers:	MVA/10.5kV/110kV
Auxiliaries transformers:	1.250kVA

Installed power plant capacity:	160.2 MW
Total installed discharge:	2.100 m^3/s

Source: *EW Włocławek, Energa OZE, website: https://energa-oze.pl/obiekty/elektrownie-wodne-duze/19959/wloclawek.*

- Tidal power plants – these make use of currents and tides as well as changes in water levels in the seas and oceans – this is the rarest form of power plant due to high capital costs.

Hydroelectric power plants have the following advantages (Niechciał, 2014):

- They irrigate the shores, thus increasing the population of fish and birds,
- They oxidize water,
- They stabilize flows,
- They leave the riverbank clean.

Disadvantages of hydroelectric power plants (Niechciał, 2014):

- Wear of available dam devices,
- Siltation of drainage channels,
- Overgrowth of reservoirs.

Water-based energy generation is currently the most reliable, safe, and efficient renewable energy source. Many of the world's hydropower plants were built nearly a century ago, and these facilities are still functional today. An example is Hoover Dam (Nevada, USA), built in 1935, which, with an installed capacity of 1,345 MW, was in 1936 the largest hydroelectric power plant of its kind in the world. With upgrades carried out between 1986 and 1993 (including the installation of two generators of 2.4 MW each), the installed capacity of Hoover Dam has increased to 2,080 MW (as of 2021) (Zimny *et al.*, 2013).

The trend to increase the production of electricity generated by hydropower takes into account the scope of implementation, e.g., catchment hydropower plants and power plants using sea currents.

Development and investment in large hydroelectric plants is contributing to an increase in energy consumption that has more than doubled in the past 20 years (Zimny *et al.*, 2013).

Poland is a water-scarce country. The average annual precipitation is about 600 mm, which ranks third from last in Europe. Water resources are small, and the average Pole has only about 1,800 m^3 per year at its disposal (Zimny *et al.*, 2013). These figures represent 1/3 of the European average and, at the same time, 1/10 of the value for the USA. Water consumption is very high, about 15 km3 of water per year

(Zimny et al., 2013). The current reservoirs are only able to hold 3 km3 of water, which represents 5% of the annual outflow of water to the sea (Zimny *et al.*, 2013).

Figure 5. *Distribution of Hydroelectric Power Plants in Poland.*

Source: *Zimny et al., 2013.*

The country's largest power plant is located in Włocławek on the Vistula River. It has 6 Kaplan turbines with a capacity of 26.7 MW each which totals 160.2 MW for the entire plant. The length of the crown is 650 m and its launching took place in 1970 (Zimny *et al.*, 2013).

Another large power plant is the facility in Solina, with a capacity of 200 MW, which has the highest dam of 82 m and the highest retention reservoir with a total area of 2,100 ha. The power plant was modernized between 2000 and 2003.

In 1970, the Żydowo power plant was put into operation. It has a 6-meter-high dam on the Radew River and two back up reservoirs: the Kamienno higher elevation reservoir and the Kwiecko lower elevation reservoir – the difference in height is 80 m – with a total power of 150 MW.

The second largest pumped-storage power plant is Porąbka-Żar, which was put into operation in 1979. It has 4 reversible Francis-type turbines with a capacity of 125 MW in generation mode and 135 MW in pumping mode.

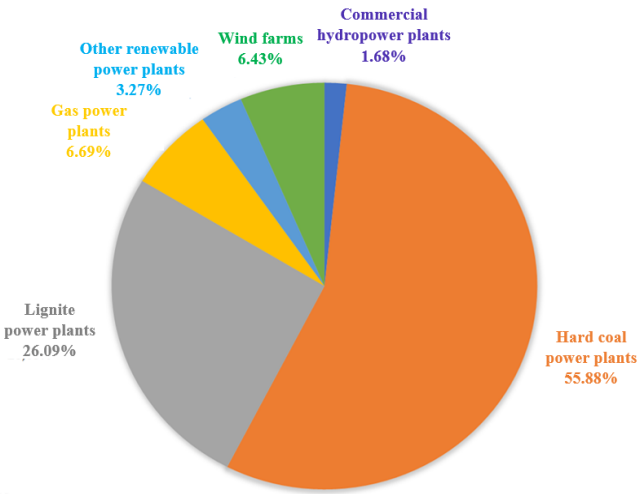
In 1983, the Żarnowiec pumped-storage power plant on the Żarnowiec Lake was commissioned with a capacity of 680 MW – 4 turbines of 170MW. It is the largest power plant in Poland regarding capacity (Zimny *et al.*, 2013).

The literature review done by Zimny *et al.* (2013) for 2010 shows a negligible contribution of hydropower to the total balance, at 3%, where fossil fuels remained at 96%. The potential for electricity generation in the basins is as follows:

- Vistula River basin – 9.3 TWh/year
- Odra River basin – 2.5 TWh/year
- Przymorze basin – 0.3 TWh/year

At the moment, the potential of rivers in Poland is used at the level of 10–12%, where the working hydropower plants generate 1.8 TWh, which is 1.68% of electricity production. The electricity production structure is shown in Figure 6 (Cenek, 2021).

Figure 6. *Elecrticity prodaction structure*



Source: *Cenek, 2021.*

4.3 Solar Energy

Solar energy is an industry that is based on harvesting solar energy. The most common forms of solar energy are photovoltaic and photothermal conversion. Photothermal conversion is based on the direct conversion of solar energy into thermal energy. Photothermal conversion can be divided into active and passive. Passive conversion involves direct airflow by convection. Active conversion, on the other hand, requires additional energy sources such as pumps.

Photothermal conversion occurs most commonly in photovoltaic cells, where the conversion of solar energy to electricity occurs. A photovoltaic phenomenon occurs in the cells, where a direct current is generated. Silicon is the most commonly used material in cells. Photovoltaic conversion is the predominant form of solar energy use. The use of solar cells is strongly dependent on environmental conditions such

as insolation levels, length of day, latitude, pressure, etc. The use of this form of energy offers a large number of advantages, such as:

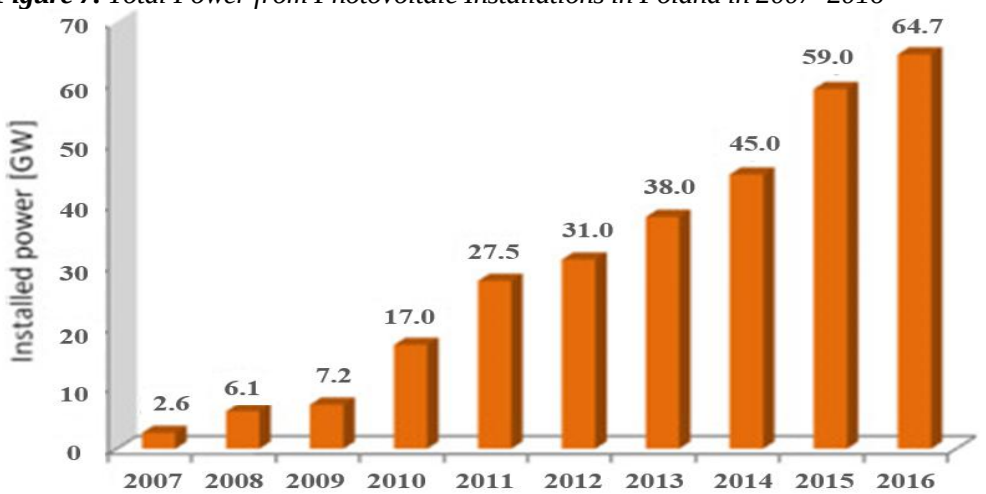
- It is a widely available source of energy,
- Operating costs are independent of energy prices,
- There are several subsidies for solar panels in Poland,
- It is possible to use the energy surplus during periods of low insolation levels,
- High installation reliability,
- There are no power outages,

The disadvantages of photovoltaic installations are as follows:

- High installation costs,
- The performance of the panels depends on the insolation,
- Panels do not work well in darkened areas located towards the north

Photovoltaic installations are the most rapidly developing form of RES. According to A. Bugała et al. in (Bugała, 2018), the total capacity of photovoltaic installations in Poland in 2014 was 45 GW. A brief history of the power obtained from photovoltaic installations is shown in Figure 7, where the upward trend and high potential of this form of RES is clearly visible.

Figure 7. *Total Power from Photovoltaic Installations in Poland in 2007–2016*

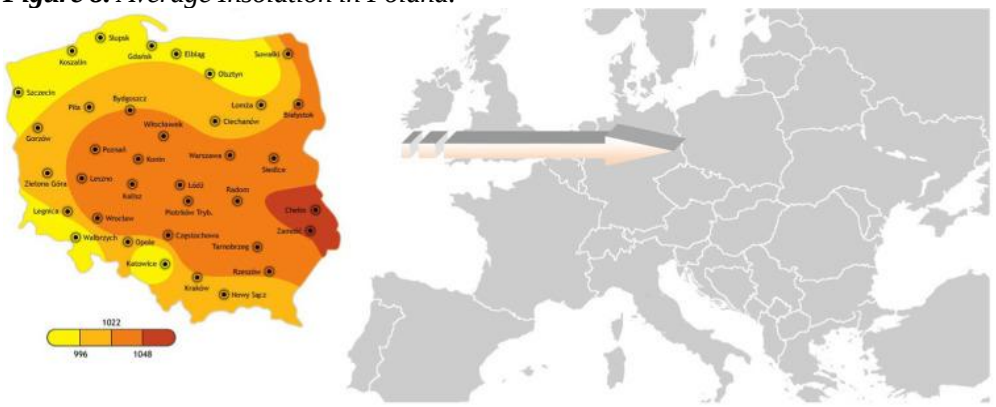


Source: *Bugała et al., 2018.*

In June–July 2021, Poland achieved a record 10% of the EU countries' solar electricity production, generating 39TWh, which is 11 TWh more than in 2018 (Rogala, 2021). This placed Poland among the eight dominant EU countries in solar electricity production. This top group also includes Estonia, Germany, Spain, Portugal, Hungary and Lithuania (Rogala, 2021).

The power output also depends on the geographical location and external factors such as insolation and hours of sunshine. Figure 8 shows an illustrative map of Poland with marked solar zones.

Figure 8. *Average Insolation in Poland.*



Source: *Bugała et al., 2018.*

Globally, according to the European Photovoltaic Industry Association report, the countries with the fastest photovoltaic growth are Germany, China, Japan, and the United States (Bugała *et al.*, 2018). Dynamic growth of photovoltaics has also been recorded in the Asian market, mainly in China. By the end of 2017, they managed to exceed 70GW, while Germany generated 38GW. For the other dominant states, the resulting capacities are 18.3 GW for Italy, 5.6 GW for France, and 5.4 GW for Spain (Bugała *et al.*, 2018).

The largest photovoltaic farm is a power plant in San Luis County (USA, California), which produces a maximum of 550MW (Bugała *et al.*, 2018). However, the maximum power is achieved by the Desert Sunlight farm (California, USA) with a maximum capacity of 55 0MW (Bugała *et al.*, 2018).

Also of interest is the Solar Star (Rosamond, California) project, which uses mono-axis tracking systems that allow the spatial repositioning of silicon modules. Its maximum capacity is 597 MW.

4.4 Biomass

Biomass is the fraction of biodegradable products, wastes, products and residues from agricultural, forestry and industrial production and biogas generated from municipal and industrial waste. Biomass includes: wood, straw, animal manure, sewage sludge, seaweed, organic waste, and vegetable oils. A characteristic feature of biomass is the so-called zero CO_2 balance. Although harmful carbon dioxide is

emitted during combustion, vegetation takes CO_2 from the atmosphere through photosynthesis for the purpose of growth (biomass production).

The advantage of biomass is that it does not contain toxic sulphur compounds compared to conventional fuels. Another advantage is the ability to use problematic waste, such as sewage sludge, reducing disposal costs. The disadvantage of this form of energy is its relatively low calorific and heating value. Biomass is mainly produced in rural areas, thus benefiting farmers financially. Due to its ubiquity, biomass has the most significant potential for use as an energy source in Poland and worldwide.

According to Bełdycka-Bórawska *et al.* (2021), biomass energy accounts for as much as 15% of the world's energy consumption, and its use is very diverse and depends on the country, from 2–3% in developed countries and up to 35% in developing countries. The biomass is mainly converted into pellets and briquettes.

Poland has a significant potential for utilization of such biomass as forest biomass, grassland, agricultural products, and special-purpose crops like poplar or willow. However, the primary source is agriculture, forestry, and the timber industry.

The potential of biomass utilization in Poland is 900 PJ/year. Compared to the EU, Poland is a leader in the use of biomass, the share of which is as high as 70% (Bełdycka-Bórawska et al., 2021), much higher than the EU average. Favorable climate and soil conditions are conducive to this.

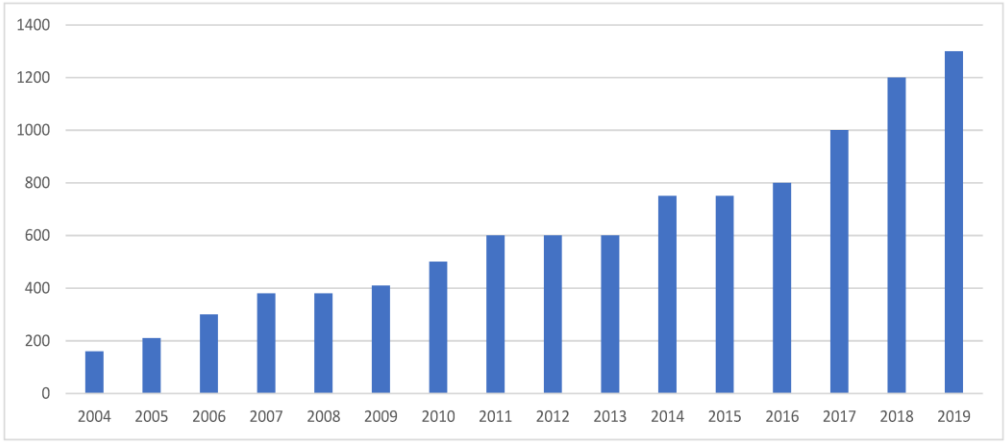
However, according to Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, EU countries, including Poland, are obliged to increase the share of RES in gross final energy consumption to 15%.

Unfortunately, this share is lower than the overall EU level, which is 20%. The wide range of biomass diversity and processing capacity make it ideal for thermal energy production, especially in the local market. The use of biomass is becoming more and more economically viable every year.

Its use in villages can be vital to the economy, where biomass from agricultural crops should play an important role. Poland has a large potential for biomass production, because as much as 93% of the country is rural, and 65% of the land is arable. Meanwhile, there are some factors hindering the development of biomass as a form of RES in Poland.

The main problem is that importing foreign pellets is cheaper than Polish production. Imports are mainly from countries outside the EU such as Russia, Ukraine and Belarus. However, pellet production is increasing, and its share is shown in Figure 9.

Figure 9. *Pellet production in Poland (thousand tons) in 2004–2019.*



Source: *Bełdycka-Bórawska, et al, 2021.*

4.5 Discussion

Renewable energy sources leverage natural and inexhaustible resources, offering a sustainable alternative to traditional fossil fuels. They enable the emission-free generation of electricity or thermal energy, contributing to environmental protection and energy sustainability. The main categories of RES include wind, hydro, geothermal, solar, and biomass energy. Each energy type has distinct characteristics that suit specific geographical and climatic conditions. For instance:

- **Wind energy** is optimal in regions with consistent and intense wind patterns.
- **Hydropower** is most effective in areas with abundant water resources and suitable terrain for dam construction.
- **Geothermal energy** relies on underground heat and is primarily used in tectonically active regions.
- **Solar energy** thrives in areas with high solar insolation.
- **Biomass energy** depends on the availability of organic material, making it ideal for agricultural or forested areas.

Integrating these energy types allows for a diversified and resilient energy portfolio tailored to local resource availability.

The utilization of renewable energy sources (RES) in Poland is steadily growing, particularly in the context of commitments stemming from the European Union's energy transition policies and efforts to reduce greenhouse gas emissions. Despite its historical reliance on coal, Poland is expanding its RES infrastructure to meet sustainable development goals and achieve climate neutrality.

The development of renewable energy in Poland will be crucial for achieving climate goals and reducing dependence on fossil fuel imports. Significant growth is particularly expected in photovoltaics and offshore wind energy. Financial support from EU funds and investments in modern technologies can accelerate Poland's energy transition.

5. Limitations of the Study

The article analyses the Polish market only in general terms, without a detailed, in-depth analysis of individual renewable energy sources. The limitation of this study is undoubtedly the lack of a detailed discussion of the technology, costs, and efficiency of individual renewable energy sources.

Another limitation is the failure to take into account local geographical, infrastructural, and economic conditions, which have a key impact on the profitability and possibilities of implementing these technologies in different regions. In addition, the study does not analyze potential legal and social barriers that may significantly affect the pace and scope of implementation of renewable energy sources. The lack of these elements makes the conclusions obtained more general in nature and requires supplementation in future, more detailed studies.

6. Conclusions

Year-on-year share growth for each form of RES can be observed in Poland thanks to favorable EU policies and several subsidies. The intensive development of environmental policy is a key activity of the European Union, which contributes to an extensive system of standards that is successfully being implemented. This review shows that the most rapidly developing forms of RES in Poland are photovoltaics and wind farms. The "National Energy and Climate Plan for the years 2021–2030" sets the following targets:

- The share of RES in gross final energy consumption is to be at 21–23% (Poland is able to reach 23% after receiving additional subsidies from the EU),
- Share of RES in transport at 14%,
- 7% reduction in GHG emissions in non-ETS sectors,
- Increase of RES share in heating and cooling at the level of 1.1% on average per year.

Wind energy has the greatest potential for the development. Wind maps available in Poland show that the greatest potential is on the Baltic coast and in the Suwałki region. The potential for wind energy is also present in areas with so-called complex topography – places where wind speed increases due to local conditions, i.e., hills and valleys of southern Poland, especially the foothills. The technical potential of wind energy is primarily related to the spatial distribution of open areas (low ground width without objects that disturb air movements). In Poland, such areas are mainly

agricultural lands, which cover as much as 18 million hectares, i.e., 59% of the total area of the country (Wiśniewski *et al*, 2012).

Photovoltaics is also a rapidly growing branch of RES. The large number of subsidies for private individuals, particularly, is generating a clear interest in collectors. The predominant form of photovoltaic used in Poland is installations in private homes. A forecast by S. Adamek in (Adamek, 2021) estimates that by 2040, the installed capacity of photovoltaic systems is expected to be 16,000 MW. In addition, the outlook analysis shows that there will be compensation for changes in PV output due to changing weather conditions, and there will be a shorter period of generating more than 50% of the installed capacity compared to the present state.

The development of RES in Poland is strongly dependent on political conditions in the country. Poland still relies on coal-based power generation, and more coal-fired power units are being built. Reducing CO2 emissions is still a significant challenge for us, one that also imposes large costs on the economy.

The projected prospects for RES in Poland by 2030, although larger, still do not account for even half of the country's overall energy demand. RES in Poland should, therefore, be treated as a form of supporting energy production and a possibility to generate savings for both individuals and companies that are able to invest in RES installations and produce energy for their own needs or sell the excess energy to the grid.

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