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AN OVERVIEW OF THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN POLAND

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Purpose: The main purpose of the article is to gather important pieces of information from different sources of renewable energy sources in Poland. That may lead to further scientific research.
Design/methodology/approach: The article is cognitive in nature and the basic research methods are the analysis of reference works and surveys. The reference work studies cover the analysis of national and foreign works.
Findings: The studies presents the actual approaches for each kind of renewable energy sources. The presented overview is based on aggregation of data from actual reports and other scientific sources. It is base for further exploring of the research topic.
Research limitations/implications: The surveys discussed in this article may contribute to further empirical studies, including but not limited to initiating works to improve the renewable energy sources.
Practical implications: The practical implications of studies entail the possibility to use them to improve application of renewable energy sources in proper places and using proper facilities.
Originality/value: The main value of this article is aggregation of data for renewable energy sources. The presented overview is base on actual data.

Keywords: photo-voltaic; forecast; renewable energy sources

Category of the paper: General review, Research paper.

1. Introduction

The continuity of energy supply as an aspect of energy security ensures economic development and quality of life. Nevertheless, it cannot be ignored that the rapid development of world economies has been accompanied by irrational exploitation of natural resources, which, in turn, has caused severe disruption to the ecological balance and precipitated the

depletion of nonrenewable resources. In addition, the emission of greenhouse gases (mainly carbon dioxide) has increased due to the combustion of fossil fuels, which causes a severe imbalance in the natural environment, such as the greenhouse effect (Bednarczyk, 2021).

The currently observed significant changes in the world's energy sector make it necessary to adequately reconstruct local and regional development views. It applies primarily to Poland, where when the world is experiencing an increasingly advanced energy evolution, most of the energy produced is still obtained from non-renewable sources, including geographically concentrated large professional thermal power plants (over 70 percent of electricity in 2019) (Śleszyński, 2021).

Energy has been an important, influential factor in countries' economic and political policies and bilateral relations and the formation of legal rules as soon as it began to occupy its irrevocable place in human life. There are different types of energy - a diversity that was not present when energy was first discovered - due to the reduction of typical energy resources and environmental concerns today. Countries with energy sources elaborate on some energy policies and implement them. On the other hand, some countries with limited possibilities in terms of energy sources develop new roles for themselves in energy and play essential roles in leading world policy to not fall out of the world order (Shahzad, 2021). Environmental fossil fuels were the source of as much as 83 percent of the energy consumed in Poland in 2020. This value is five times greater than the energy obtained from RES. Poland is in the infamous first place in Europe regarding securing energy from fossil fuels (Niekurzak, 2021).

The photovoltaic market in Poland is going through a development boom. At the end of 2020, Poland was in first place in the European Union regarding the growth rate of photovoltaic power. The photovoltaic capacity installed in Poland at the end of 202 was 3936 MW, which means an increase of 2463 MW year on year and translates into an increase of 200 percent year on year. It should be taken into account that the main driver of growth are prosumers. Thus, according to Solar Power Europe, in 2020, Poland was in fourth place in terms of increasing the installed PV capacity in the European Union.

This article is structured as follows. The Introduction covers the topic and the outline of solutions. The next part deals with the basics of renewable energy sources in Poland. In the next part, the scope is on the photovoltaic market in Poland. Then the discussion is presented in turn. The last parts are Conclusions and References.

1.1. Related work

The proposed topic is a significant part of global politics. The connection between renewable energy sources and sustainable economic growth is substantial (Yikun, 2021), in Europe (Włodarczyk, 2021) or in South Asia (Aner, 2021). The area of interest is extensive, which may cause additional problems to be solved. There are many methods to be applied in the field of interests, e.g., multi-criteria method (Ulewicz, 2021), stochastic scheduling (Faraji, 2021), multi-objective optimization (Ullah, 2021), AI (Boza, 2021).

As a part of the European Union, Poland is involved in all the situations which appear in the EU countries. That causes some problems but also gives opportunities. The main problem of all renewable energy sources is integration into European (and each country's) grids (Hammons, 2008). Also, the consumption of renewable energy in economic sectors in the whole EU countries is essential (Tutak, 2022), and also by households (Piekut, 2022).

Also, as a separate country, Poland has many specific aspects for renewable energy to be solved. First of all, the support scheme for renewable resources should be known (Wysocki, 2022) or other support mechanisms (Mazurek-Czarnecka, 2022). After the support mechanisms are defined, it is necessary to plan and declare settlement conditions (Śleszyński, 2021; Szyba 2021). It is also important to include determinants of the energy development in Poland (Bednarczyk, 2021). The potential of renewable energy resources (Niekurzak, 2021).

The modernization processes of energy consumption are also in the scope of the paper (Sobocińska, 2022). The modernization processes also meet barriers (Juszczyk, 2022). Those topics are a part of local governments' policies (Rakowska, 2021) or sustainable development policy (Serowaniec, 2021). The local society may treat renewable energy sources as truth or myth in its opinions (Woźniak, 2022).

As was shown, the problem of renewable energy sources is widely spread in the scientific field of interest. Above mentioned articles show the importance of the topic and define the scope of the presented paper. The specific aspect of Poland will be shown in the other parts of the article.

2. Renewable energy sources in Poland

Technological development is inevitably related to the increasing demand for energy. In addition, the dwindling resources of fossil fuels meant a need to obtain power unconventionally - i.e., renewable energy sources (RES). Russia's war with Ukraine and the consequent lack of coal and gas supplies from Russia have shown how unfavorable the situation of countries dependent on energy imports is. Figure 1 shows the percentage dependence of individual European countries on energy imports in 2020. It can be noted that Poland is in the group of countries whose dependence on energy imports is 80,01-97,56%.

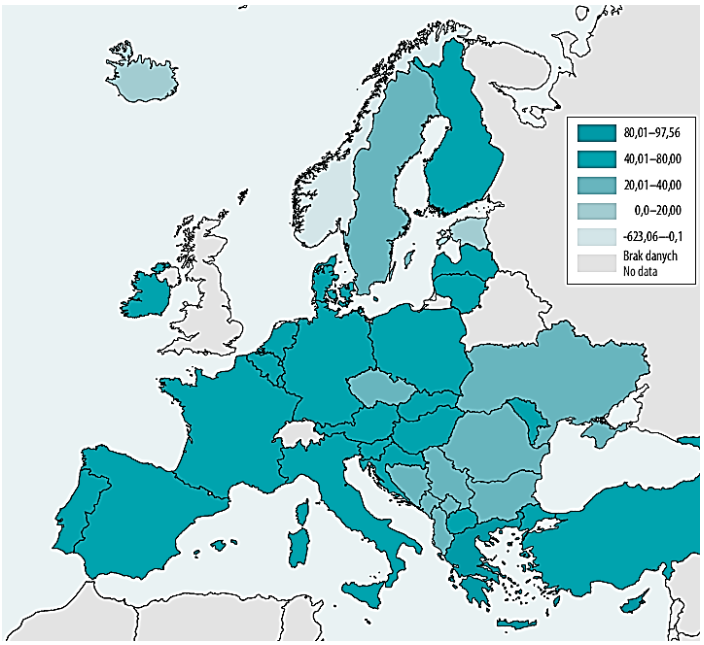

Figure 1. Dependence on energy imports in 2020.

Source: (Energy, 2022).

Renewable energy sources, i.e., those whose use is not associated with their long-term deficit. The RES resource is renewed relatively quickly - these are the so-called renewable raw materials. Renewable resources include: sun, wind, water, biomass, biogas, biofuels, and nuclear energy in a closed fuel cycle (Seroka, 2022).

Renewable energy sources include:

- solar energy (also known as solar radiation energy), which has the most significant energy potential, is mainly used to generate electricity and heat,
- wind energy,
- hydro-power,
- geothermal energy,
- biomass energy,
- energy from sand.

In Poland, in 2021, according to the Energy Market Agency, electricity production was the highest in the history of Poland and amounted to 179,4 TWh. The electricity demand was also record-breaking, reaching 180,3 TWh. Energy production in 2021 from RES was the highest in the history of Poland and amounted to 30 TWh. The structure and division of energy production sources in Poland in 2021 are presented in (Figure 2). The share of renewable energy sources in Poland's total energy production decreased to 16,7% compared to 2020, when it was 17,7%. Wind energy was responsible for more than half (54%) of RES production, the share of biomass was 15%, and photovoltaic was 13%. Within ten years, production from RES increased by 80% - from 16,8 TWh in 2012 to 30.4 TWh in 2021. Apart from photovoltaic, wind farms' most significant increase in production was observed (an increase of 250% in a decade) (Raport Transformacja energetyczna, 2022).

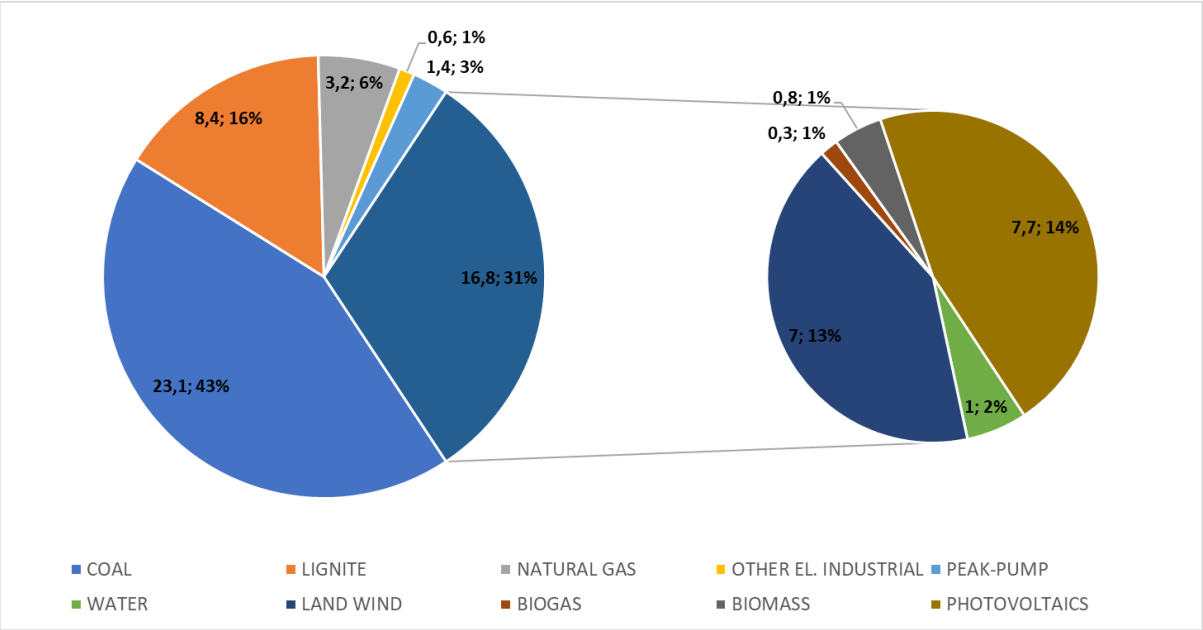

Figure 2. Share of the capacity of energy sources in Poland in 2021.
Source: (Raport Transformacja energetyczna, 2022).

In Poland, the actual legal act regulating the development of renewable energy sources is the Act of 20 February 2015 on renewable energy sources. This act adjusts to the Polish legal system Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. The goals behind the entry into force of the RES Act were primarily (Raport Polska energetyka, 2022):

- increasing energy security and environmental protection as a result of the effective use of renewable energy sources rational use of renewable energy, taking into account the implementation of the long-term economic development policy of Poland,
- fulfillment of obligations resulting from concluded international agreements and increasing innovation and competitiveness of the national economy,
- shaping mechanisms and instruments support the production of electricity, heat or cold, or agricultural biogas in installations of renewable energy sources.

The European Union's climate and energy policy, including its long-term vision of striving for EU climate neutrality by 2050, significantly shapes the national energy strategy. In 2014, the European Council maintained the direction of combating climate change and approved four targets for the 2030 perspective for the entire EU, which, after the revision in 2018 and 2020, are as follows:

- reduction of greenhouse gases (GHG) emissions by at least 55% compared to 1990 emissions,
- at least 32% share of renewable sources in gross final energy consumption,
- increase in energy efficiency by 32,5%,
- completion of the internal EU energy market.

The above objectives are the EU's contribution to implementing climate agreements. Of crucial importance for current policies and actions is the so-called Paris Agreement. It results in the need to stop the increase in the average global temperature below two degrees Celsius compared to pre-industrial levels and keep it no more than 1,5°C. During the 24th conference (COP24) in December 2018, during the Polish Presidency, the so-called Katowice climate package implemented the Paris Agreement. The transformation resulting from the Paris Agreement must be fair and solid is essential. The goal of the state's energy policy is energy security while ensuring the competitiveness of the economy and energy efficiency and reducing the impact of the energy sector on the environment with the optimal use of its energy resources.

Energy security means the current and future satisfaction of customers' needs for fuels and energy in a technically and economically justified manner while maintaining environmental protection requirements. The present and future guarantee of the security of the supply of raw materials, production, transmission, and distribution of energy, i.e., the complete energy chain, is essential. The fuel cost is hidden in every activity and product produced in the economy. Therefore energy prices translate into the competitiveness of the entire economy. At the same time, emissions of pollutants from the 2nd energy sector impact the environment. Thus creating the energy balance must be carried out with due regard to this aspect. Poland's energy policy until 2040 (PEP2040) sets the framework for the energy transformation in Poland. PEP2040 considers the scale of challenges related to the adjustment of the national economy to the EU regulatory conditions associated with the 2030 climate and energy goals, the economic recovery plan after the COVID pandemic, the European Green Deal, and the pursuit of climate neutrality as possible. PEP2040 describes the state and conditions of the energy sector. Then, three pillars of PEP2040 were identified, on which the eight specific objectives of PEP2040 were based, along with the activities necessary for their implementation and strategic projects.

Poland's energy transformation will be based on three pillars:

1. Just Transition - it will mean providing new development opportunities for regions worst hit by the harmful effects of the transition while providing new jobs and building new industries. Individual energy consumers will also participate in the transformation, as they will be shielded from the increase in energy prices and encouraged to actively participate in the energy market.
2. Zero-Emission Energy System - will be implemented through the implementation of nuclear energy and offshore wind energy, increasing the role of distributed and civic power while unambiguously ensuring energy security through the temporary use of energy technologies based, among other things, on gaseous fuels.
3. Good Air Quality - will be implemented through the departure from fossil fuels, thanks to investments in the transformation of the heating sector, electrification of transport, and promotion of passive and zero-emission houses, using local energy sources.

PEP2040 includes eight specific objectives:

1. optimal use of own energy resources,
2. expansion of the generation infrastructure and electricity network,
3. diversification of supplies and growth of the network infrastructure of natural gas, crude oil, and liquid fuels,
4. development of energy markets,
5. implementation of nuclear energy,
6. development of renewable energy sources,
7. development of district heating and cogeneration,
8. improvement of energy efficiency.

The PEP2040 adopted several detailed indicators, which were considered as a measure of the achievement of the objective:

- no more than 56% of coal in electricity generation in 2030,
- at least 23% RES in gross final energy consumption in 2030, item implementation of nuclear energy in 2033,
- reduction of GHG emissions by 30% by 2030 (compared to 1990),
- reduction of primary energy consumption by 23% by 2030 (compared to PRIMES forecasts from 2007).

PEP2040 determines the appropriate distribution of energy sources in general production in individual countries. An in-depth analysis is necessary to understand the detailed conditions for individual RES. Its purpose is to define the needs and requirements of separate energy sources.

3. A detailed overview of renewable energy sources

3.1. Wind energy

Wind, i.e., the kinetic energy of moving air, has been used by man for centuries primarily as mechanical energy in windmills or wind pumps. The renewable nature of wind seems obvious. You can never talk about its long-term deficiency or complete exhaustion. Wind farms are most often built on farms located on land or offshore - at sea or in river deltas. Therefore, we can talk about the following:

- onshore,
- offshore.

The leading countries using wind energy are China, and the United States (Energy, 2022). In 2021, the capacity of Chinese wind farms increased by 170%. In Europe, the UK is leading the way, investing primarily in offshore wind energy, i.e., offshore. Other countries, i.e., Sweden and Germany, focus on onshore wind energy. Poland is in the 12Th position.

In July 2021, the European Commission presented a 2030 renewable energy target of 40%, up from the current 32%. This means that to achieve this ambitious target, the EU will need to double its annual wind capacity from 15 GW to 30 GW per year. According to WindEurope data, wind currently meets 16% of electricity demand in Europe, and in many countries, much more: Denmark - 48%; Ireland - 38%; Germany - 27%; Portugal - 24%; Spain - 22%. The IEA predicts that by 2027 wind will become Europe's number one energy source. In 2021, the leaders in the field of onshore wind farm installations were Sweden (2.1 GW), Germany (1.9 GW), Turkey (1.4 GW), and France (1.2 GW). Notably, the realistic scenario developed by WindEurope indicates that nearly 90 GW of new onshore wind capacity will be installed in Europe in 2022-2026, i.e., an average of 17.4 GW per year (Energy, 2022).

The figure 3 presents the wind energy zones in Poland.

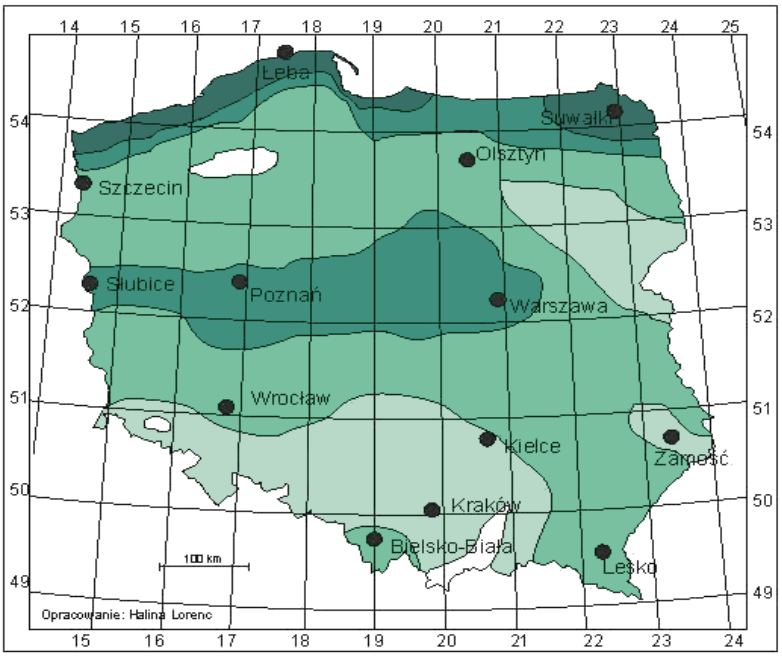

Figure 3. Wind energy zones in Poland.

Source: Raport Transformacja energetyczna w Polsce. Edycja 2022.

Energy generated from wind is considered clean energy because there is no emission of harmful pollutants during its generation. This is not the only benefit of wind energy development. The development of wind energy will directly translate into the competitiveness of the domestic economy in the international arena, will contribute to a decrease in energy prices, and will additionally generate new jobs.

Starting in 2016, Poland has faced numerous barriers preventing the dynamic development of onshore wind energy. These include, for example, the distance rule, the rules for agreeing on the connection of investments to the national power system, or the issues of assessing the impact of projects on the environment. All problems related to the role of the local community in the investment procedure are also significant. By the EU target binding for Poland, a 55% reduction in emissions in 2030 compared to 1990 will require over 18 GW of onshore wind power.

The development of onshore wind energy in Poland is also supported by the results achieved by the industry this year. In January, wind energy satisfied Poland's energy needs at the level of 30-35%, and in February, almost 50%. Moreover, the analyzes carried out by the Jagiellonian Institute clearly show that the share of onshore wind energy significantly reduces the price per 1 MWh on the Day-Ahead Market. As indicated by the Agency Energy Market, in December 2021, 5 new wind installations with a total capacity of 151,94 MW were built, and in the entire In 2021, 48 new wind installations with an installed capacity of 1071,75 MW appeared.

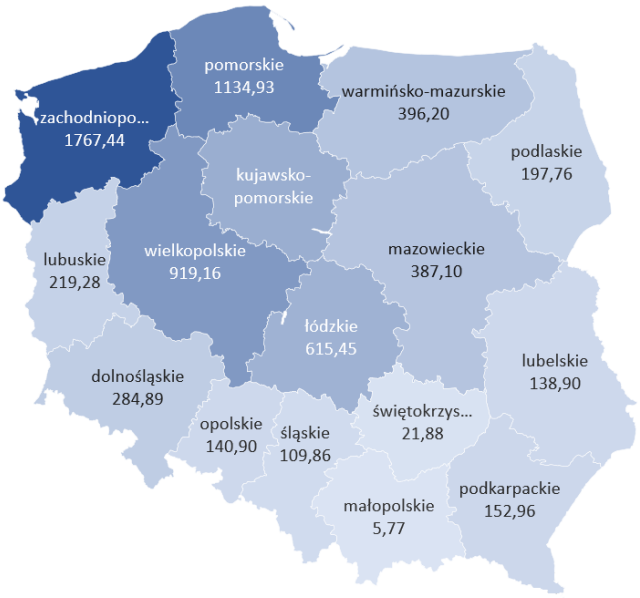

Figure 4. Power of energy in wind farms in individual voivodeships as of 31.12.2021.

Source: Raport Transformacja energetyczna w Polsce. Edycja 2022.

The advantages and disadvantages of wind energy are presented in the table 1.

Table 1.
The advantages and disadvantages of wind energy

Cons	**Pros**
breaks in the operation of windmills - performance fluctuations depending on weather conditions	no harmful emissions
a threat to the life of bats and birds, especially in the case of improperly located wind turbines	short construction time
intervention in the landscape (large area occupied by wind farms)	low operating costs
low efficiency of a single windmill (approx. 2-4 MW)	possibility of running a business (e.g., growing cereals) in the vicinity of windmills
noise (concerns older structures)	

Source: Own study.

3.2. Water energy (hydro-power)

Hydro-power is nothing more than the economically used mechanical energy of flowing water. At present, hydro-power is usually converted into electricity. Water energy can also be used directly to drive machines. In Poland, water energy has a very long tradition. It can be divided into the so-called large and small hydro-power (SHP).

The principle of operation of hydropower plants is simple and consists in damming up water using dams. The dammed water finds its outlet in pipes and hits the turbines at high speed, causing the blades to rotate. Kinetic energy is thus converted into mechanical energy. It then goes to a generator that converts it into electricity. The next and last element of the entire process of electricity production in a hydroelectric power plant is the transfer of the generated electricity to the power grid.

Water energy is an element of the energy industry of every country. Hydro-power plants can be built both on rivers and at sea. Due to the source of energy, power plants can be divided into:

- inland water power plants (river),
- power plants that obtain energy from sea waters (e.g., tides, waves),
- power plants using both inland and seawater.

In hydro-power, the following types of power plants are distinguished (Mikulski, 1998):

- hydro-power plants (EW): run-of-the-river (RRP) or reservoir (RP),
- hydro-power plants with a pump unit (PU-P),
- pumped-storage power plants (PSP), also known as pumped storage,
- tidal power plants (TP).

Hydro-power in Poland includes all hydro-power plants that use the natural flow of rivers, regardless of the method of obtaining the head, power, and size of the head. Renewable energy sources do not include pumped-storage water power plants and run-of-the-river power plants with a pump unit due to the need to purchase energy for pumping from other sources (Matuszek, 2005).

Due to their size, power plants can be divided into (Mikulski, 1998):

- large hydro-power plants with a capacity of over 10 MW,
- small hydro-power plants (MEW) with a capacity of 1MW - 10 MW,
- mini hydro-power plants with a capacity of up to 1 MW,
- micro hydro-power plants with a capacity of less than 200 kW.

However, taking into account the height of water drops, i.e., the differences between the upper level of the water reservoir and the lower one, large power plants can be divided into:

- low-head hydro-power plants (up to 15 meters),
- hydro-power plants with an average head (between 15 and 50 meters),
- high-fall hydro-power plants (above 50 meters).

The potential of hydro-power is evenly distributed throughout the country. About 68% occur in the Vistula river basin, while in the Oder basin, about 17% (Insolation, 2022). Rivers with high energy potential include the Vistula, Dunajec, San, Bug, Odra, Bóbr and Warta.

The advantages and disadvantages of hydro-power are presented in the table 2.

Table 2.
The advantages and disadvantages of hydro-power

Cons	Pros
the use of hydro-technics harms the migration of fish - although the use of fish passes in hydro-technical facilities, the natural process of their migration is disturbed	water energy is an ecological source of energy
the need to interfere with the environment during the construction of a hydroelectric power plant	free kinetic energy and low cost of electricity production - kinetic energy are generated by water that naturally flows in riverbeds. However, after the construction of a hydro-technical facility, renewable energy is very cheap to obtain
high costs associated with the construction of the power plant - unfortunately, the initial investment in a renewable source of water energy is much more expensive than other ecological power plants	the need to use dams to protect against floods - with an appropriate water drop, water damming is used, simultaneously allowing you to regulate the level of rivers. This is very important, especially in the event of a flood wave
work noise	the ability to store energy - a source of renewable energy, which is water, not only produces electricity for current needs but also allows energy storage
changes in water levels that may generate landslides	
siltation of rivers, which is very undesirable from the point of view of creatures living in water	

Source: Own study.

3.3. Solar energy

Solar energy is unlimited by the availability of resources, it reaches the Earth through solar radiation. It is then processed in a photovoltaic, photo-chemical, or photo-thermal conversion process. Solar energy comes to the Earth in the form of solar radiation. It is readily available energy. Unfortunately, the flux density getting to the Earth depends on the geographical location, season, and time of day. In Poland, the Institute of Meteorology and Water Management researches solar radiation. The PN-B-02025 standard shows that the average value of total radiation intensity for Poland during the year is 993,5 kWh/m^2. The best solar conditions exist on the Szczecin and Central Coasts and in the east of Poland - Zamojszczyzna, Polesie, etc. The map of Poland's insolation is shown in figure 5.

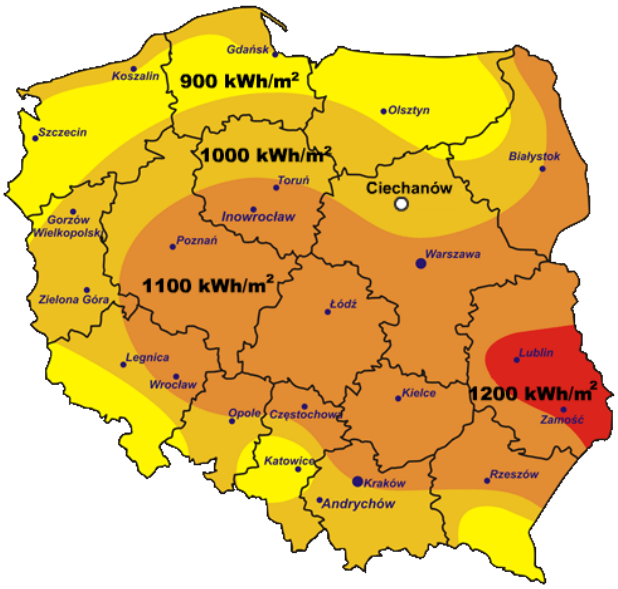

Figure 5. Insolation in Poland in 2021.

Source: Insolation, 2022.

Solar energy can be used in three ways:

- Photo-chemical conversion, i.e., the change of solar radiation energy into chemical energy. It is not widely used in technology but occurs in living organisms. The efficiency of this process is estimated to be around 19-34%.
- Photo-thermal conversion - direct change of solar radiation energy into thermal energy. Depending on whether additional energy sources are used for further distribution of the obtained power, passive photo-thermal conversion and active photo-thermal conversion are distinguished. In the case of dynamic photo-thermal conversion, the flow of the heat carrier is carried out using pumps powered by additional energy sources. In contrast, in the case of passive conversion, the heat carrier flow takes place by convention.
- Photovoltaic conversion - it is used in photovoltaic cells. These are devices that directly convert solar energy into electricity. The exchange is possible thanks to the use of semiconductor p-n junctions. The photon that strikes the silicon wafer is absorbed by the silicon, knocking the electron out of its position and causing it to move. This movement is the flow of electric current.

The advantages and disadvantages of solar energy are presented in the table 3.

Table 3.
The advantages and disadvantages of solar energy

Cons	Pros
relatively high cost of devices	unlimited energy resources (solar radiation) - it can be obtained even when it is raining or cloudy
cyclicality and uneven use (available energy depends on the time of day and year)	photovoltaic installations have a negligible negative impact on the natural environment due to the lack of pollution with waste and combustion products
problems with storing more electricity	the universality of this technology means that it can be installed almost anywhere by selecting the appropriate modules
the value of the intensity depends on the angle of incidence of the sun's rays	the possibility of direct conversion into various forms of energy (heat, electricity)
quite low efficiency of photovoltaic modules	no need to use fuel and transport energy
the dependence of solar radiation on atmospheric pollution, cloud cover	surplus energy can be collected and sold to external suppliers
	low operating costs
	lack of mechanical devices for processing electricity and noise related to their operation
	allows to significantly reduce the emission of harmful greenhouse gases into the environment because it is a zero-emission source
	allows you to significantly reduce the emission of harmful greenhouse gases into the environment because it is a zero-emission source

Source: Own study.

The following types of photovoltaic installations are distinguished:

- micro-installations - i.e., installations with a total installed capacity not exceeding 50 kW. These are the so-called prosumer installations. The total capacity of micro-installations amounted to approx. 6 GW;
- small installations - installations with a capacity of 50 kW - 1 MW. The power of facilities installed in Poland reached a value of over 1,5 GW;
- photovoltaic farms - over 1 MW - the total installed capacity has been estimated at almost 200 MW.

In Poland, the largest share in the photovoltaics market is held by micro-installations, which in 2021 accounted for less than 80% of the power installed in photovoltaics. In the entire power structure of renewable energy sources, in 2022, photovoltaic installations account for over 50% (Fig. 7). The total installed capacity of photovoltaics in Poland at the end of July 2022, according to the data of the Energy Market Agency, amounted to 10,586 GW.

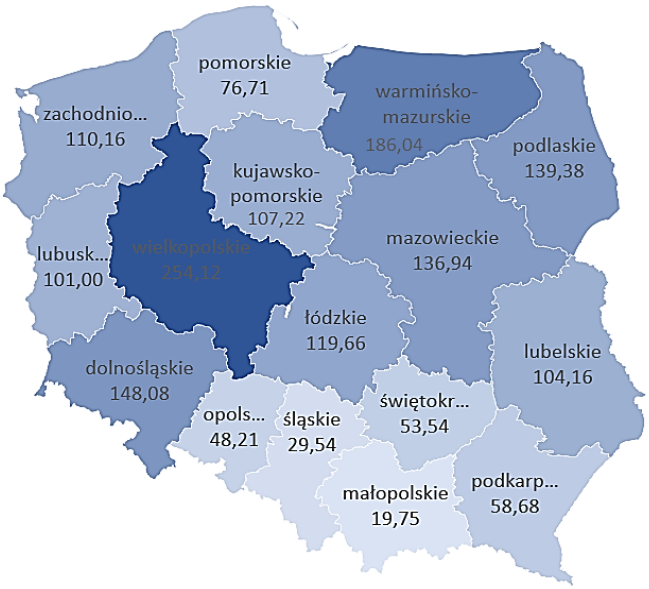

Figure 6. Installed power in photovoltaic installations in individual voivodships as of the day 31.12.2021.

Source: Own study.

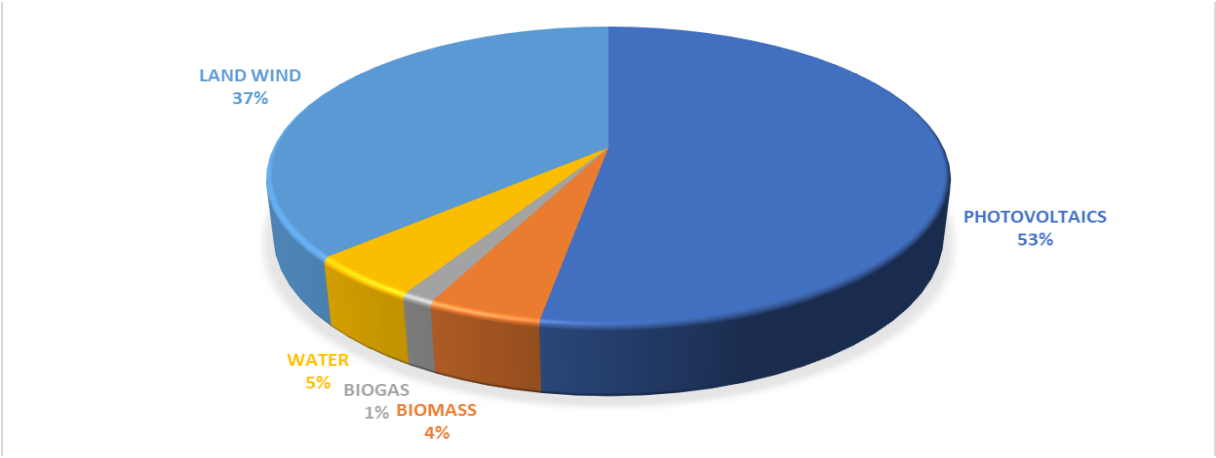

Figure 7. Share of the capacity of energy sources in Poland in 2021.

Source: Own Study.

The development of the photovoltaic market in Poland is highly dynamic. At the end of 2021, Poland was ranked second in Europe with an increase in installed capacity of 3,7 GW. In Europe, the most significant increase was recorded in Germany, which recorded an increase of 5,3 GW (Fig. 8).

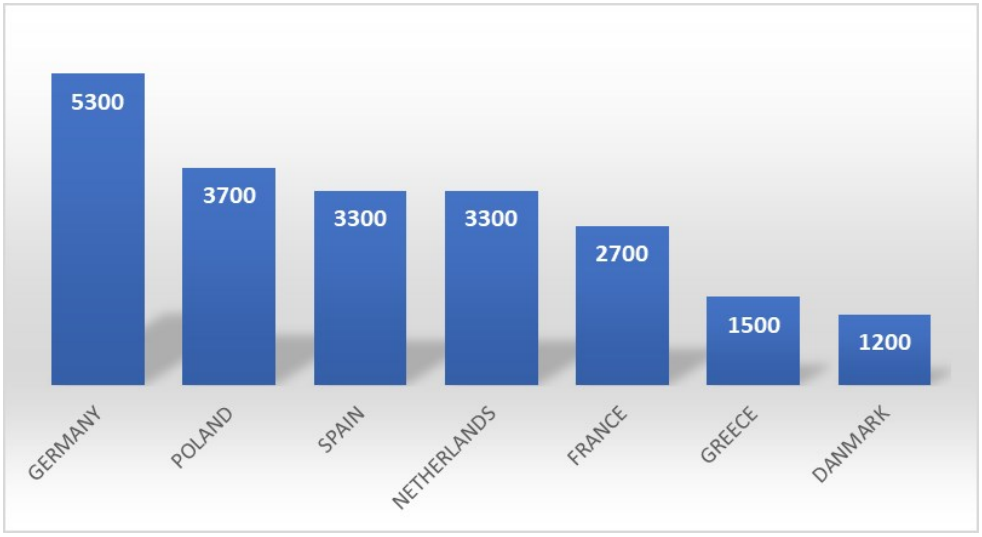

Figure 8. Increases in installed capacity in individual countries in 2021.

Source: Own study.

The installed capacity of photovoltaics in Poland is mainly due to prosumer micro-installations, which account for about 76% of all installations in the country. 2021 was a record year for new connections of prosumer photovoltaic installations. According to ARE, at the end of 2021, it amounted to over 845,000 units, which means an increase of over 89% compared to 2020. Such an increase was mainly due to the change in the settlement system from net metering to net billing. The "Clean Air", "My Electricity", and "My Heat" programs also provided great support for prosumers. Since 2018, there has been a noticeable increase in the installed photovoltaic capacity in small RES installations, while other renewable sources remain almost constant. Since 2019, new additions have reached several hundred megawatts per year in photovoltaics.

At the same time, since this year, PV has been indisputably in first place, and its outlook for the coming years is also optimistic.

The key market segment that uses small installations is business prosumers or self-producers of energy from RES. These include any company or enterprise that, thanks to its own RES installation, produces electricity for its own needs, thus reducing the cost of purchasing energy from the grid.

Table 4.
The largest photovoltaic farms in Poland in 2022

Localization	Power	Year of commissioning	Owner
Zwartowo	204 MW	2022	Stigma Sp. z o.o.
gm. Brudzew	69,999 MW	2021	ZE PAK
gm. Witnica	64,600 MW	2021	Alternus Energy Group
gm. Wielbark	62 MW	2022	Energa Wytwarzanie
Stępień (gm. Braniewo)	58 MW	2022	Wento
Żydowo/Polanów	29,999 MW	2021	Better Energy
Postomino	29,961 MW	2021	Better Energy
Bogucice	8,054 MW	2022	SOLAR-R
Borki Wielbarskie	7,987 MW	2021	Energa OZE
Jaworzno	5,000 MW	2020	Tauron
Prochowice	4,677 MW	2021	EWG Elektrownie Wiatrowe
Czernikowo	3,770 MW	2015	Energa OZE

Source: Own study.

3.4. Biomass energy

According to the content of the amended Art. 2 point 3 of the Act of 7 June 2018 on renewable energy sources, the term biomass should be understood as: "The biodegradable part of products, waste or residues of biological origin from agriculture, including plant and animal substances, forestry and related industries, including fisheries and aquaculture, processed biomass, in particular in the form of briquettes, pellets, torrefied and biochar, as well as the biodegradable part of the industrial or municipal waste of plant or animal origin, including waste from waste treatment installations and waste from water treatment and sewage treatment, in particular sewage sludge, following the provisions on waste in the scope of qualifying part of the energy recovered from the thermal treatment of waste".

Biomass is an attractive alternative to coal, mainly due to the lower amount of pollutants produced. It is characterized by a zero balance of CO2 emissions and lower emissions of sulfur dioxide, carbon monoxide, or nitrogen oxides than fossil fuel combustion. Biomass can be used in three ways (Janowicz, 2006):

- combustion in boilers (straw, pellets, wood chips, wood),
- cooperation with conventional energy carriers (coal, gas, and others),
- combustion of products resulting from the processing of biomass (biogas, biodiesel, etc.).

The following types of biomass are most often used for energy purposes:

- wood of low technological quality and waste,
- sewage sludge,
- municipal waste,
- animal excrements (manure, liquid manure and slurry are the raw material for biogas production),
- straw, cake, and other agricultural waste,
- energy crops (including seaweed grown specifically for energy purposes).

The advantages and disadvantages of biomass energy are presented in the table 5.

Table 5.
The advantages and disadvantages of biomass energy

Cons	Pros
low energy value	biomass is safe for the environment
dioxin emission	low costs
emission of nitrogen oxides during the combustion of biofuels	unlimited access
reducing biodiversity risk	independence from weather conditions
	products from which biomass is produced can also be grown on wasteland
	many biomass fuels - such as wood and plants - can be regenerated

Source: Own study.

In the European Union, the energy industry must use biomass as fuel. However, due to the insufficient supply of this green fuel in Europe and its high prices, the practical consequence of these regulations is the import of biomass from Asia or Africa, which naturally negates the benefits of reducing emissions. Biomass is also imported in Poland, mainly from countries such as Russia, Ukraine, Hungary, Bulgaria, and Latvia (about 85% of biomass comes from imports). Biomass in Poland has excellent potential for development, which should not be neglected. Poland has a solid agro-sector; unfortunately, it is difficult to discuss a particularly favorable situation regarding soil quality. Because in Poland, the most fertile chernozems (I valuation class) occupy only 0.75%, while 40% of soils belong to class IV, 23% to class III and V, and 11% to class VI lands. Therefore, it is necessary to fertilize lower-quality agricultural land to obtain high yields.

This situation may therefore be beneficial for producers of energy crops, which, as we already know, do not require high-quality land (soils with low valuation are used for biomass crops - class V and VI). In addition, biomass in Poland can be obtained from the forest, agricultural and production waste, or garbage. The most effective model for the operation of biomass energy is its use, especially in local heating. However, to make biomass the leading source of green energy in Poland, systemic support is necessary, thanks to which it will be possible to build local logistic chains covering producers and recipients. Installed capacity in biomass power plants in individual voivodeships as of 31.12.2021.

Biogas can be used for energy purposes locally by coupling the generated fuel with a biogas burning unit or, after cleaning, introduced into the gas network and, after transmission, further used for energy purposes.

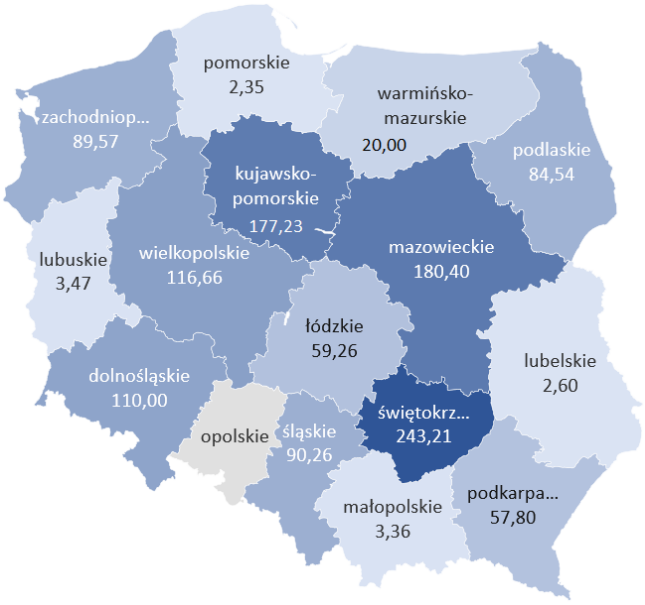

Figure 10. Installed power in biomass power plants in individual voivodships as of 31.12.2021. Source: Own study.

3.5. Energy from biogas

Biogas is a gas from processing organic compounds contained in biomass. It is a secondary source resulting from biomass processing using various processes. The most common biogas production technique is methane fermentation, where in anaerobic conditions, physicochemical processes supported by methane bacteria decompose organic matter into gaseous form.

Biogas is a combustible gas, so it can be used as a fuel to drive a gas turbine to produce electricity, as a fuel used in a boiler to generate heat, or, more often, as a fuel for a cogeneration system engine, where electricity and heat are produced in one process.

Biogas can be compressed adequately after cleaning and used as fuel for motor vehicles in transport. Such solutions are well known in Sweden, as well as in Germany and Austria.

Biogas can be characterized as:

- Composition of biogas - The volumetric composition of biogas strongly depends on the type of biomass from which it was produced, and it consists only of components made of organic matter. Biogas (raw) consists of approx. 50-65% methane (CH_4), 30-45% carbon dioxide (CO_2) and other components in trace amounts such as water vapor $(H_2)O)$, hydrogen sulfide (H_2S), nitrogen (N_2), hydrogen (H_2), oxygen (O_2).
- Mass of biogas - Knowing the volumetric composition of biogas, we can determine the mass of biogas with a high approximation. Under normal conditions (pressure and ambient temperature respectively 1013,25 hPa and 273,15 K), the mass of biogas is approx. 1,2 kg/m.

- Calorific value - The calorific value of biogas results directly from the methane content in the biogas. A typical biogas has a calorific value of 19-23 MJ/m^3. Knowing the calorific value and biogas production, we can determine the amount of primary energy generated in a given time unit, and then, after taking into account the efficiency of the primary energy conversion system in the final one, we can determine the amount of electricity and/or heat that can be produced. Assuming conversion efficiency at the level achieved by cogeneration systems (CHP) currently on the market, we can obtain approx. 2,2 kWh of electricity and approx. 8 MJ of heat from one m3 of biogas.
- Other parameters of biogas - colorless, odorless. It consists of combustible and non-combustible gases; only methane gives energy gain.

The following types of biogas can be distinguished:

- landfill biogas - it is created from the decomposition of organic compounds stored in landfills;
- sewage biogas - it is produced as a result of the decomposition of organic compounds of sewage sludge;
- municipal biogas - it is made as a result of the decomposition of organic compounds of biodegradable municipal waste (e.g., collected leaves from parks);
- agricultural biogas - is produced as a result of the decomposition of raw materials of agricultural origin.

The list of advantages and disadvantages of biogas is presented in the table 6. And the power installed according to the use of biogas is shown in figure 11.

Table 6.
Advantages and disadvantages of biogas

Cons	**Pros**
methane is a rather dangerous gas due to its instability	it is 100% clean energy
biogas production technology still causes large heat and energy losses at the production stage	for this biogas production, methane-fermentable organic waste is first used
biogas is a fuel that is difficult to produce on a large scale	getting rid of organic waste and distributing fertilizer ingredients
	reduces the amount of soil and water contamination

Source: Own study.

Figure 11. Installed capacity in biogas power plants in individual voivodeships as of 31.12.2021. Source: Own study.

4. Discussion

The presented types of renewable energy sources in Poland differ from each other. The differences lie in the technologies used, the complexity of generating installations, and the availability (conditions) of particular energy sources. A careful selection of RES is needed. It depends on organizational and technical issues.

Each renewable energy technology has its advantages and disadvantages. As part of the investment implementation, it is necessary to include them in the implementation project. The development of individual RES in Poland is still ongoing. The most common is photovoltaics and obtaining energy from wind and water, partly due to technology and issues related to terrain and weather conditions.

The development potential of RES is growing along with the energy crisis in Europe and the world. Reviewing the RES development potential in Poland is the starting point for forecasting the development of these energy sources.

5. Conclusions

The article presents an overview of Poland's types of renewable energy sources. Analyzing individual RES's potential, advantages, and disadvantages allows you to familiarize yourself with the subject and is a starting point for further research.

Analyzing technological conditions and implementation possibilities of individual energy sources is essential in determining the further development of unique technologies and the possibility of creating a prognosis of their development potential.

The direction of further development of this publication is determined by creating forecasts for using particular RES in the future, considering the guidelines of the European Union.

References

1. Anser, M.K., Shabbir, M.S., Tabash, M.I., Shah, S.H.A., Ahmad, M., Peng, M.Y.-P., Lopez, L.B. (2021). Do renewable energy sources improve clean environmentaleconomic growth? empirical investigation from south asian economies. *Energy Exploration & Exploitation, vol. 39, no. 5,* pp. 1491-1514.
2. Bednarczyk, J.L., Brzozowska-Rup, K., Luściński, S. (2021). Determinants of the energy development based on renewable energy sources in poland. *Energies, vol. 14, no. 20,* p. 6762.
3. Boza, P., Evgeniou, T. (2021). Artificial intelligence to support the integration of variable renewable energy sources to the power system. *Applied Energy, vol. 290*, p. 116754.
4. Energy 2022 (2022).
5. Faraji, J., Hashemi-Dezaki, H., Ketabi, A. (2021). Stochastic operation and scheduling of energy hub considering renewable energy sources' uncertainty and n-1 contingency. *Sustainable Cities and Society, vol. 65,* p. 102578.
6. Hammons, T.J. (2008). Integrating renewable energy sources into european grids. *International Journal of Electrical Power & Energy Systems, vol. 30, no. 8,* pp. 462-475.
7. Insolation. Online (2022). 28.11.2022.
8. Janowicz, L. (2006). *Energetyka, No. 8,* pp. 601-604, ISSN 0013-7294.
9. Juszczyk, O., Juszczyk, J., Juszczyk, S., Takala, J. (2022). Barriers for renewable energy technologies diffusion: empirical evidence from Finland and Poland. *Energies, vol. 15, no. 2,* p. 527.
10. Matuszek, W. (2005). Wykorzystanie energii wodnej jako elementu rozwoju energetyki odnawialnej. *Elektroenergetyka, vol. 1, no. 52,* pp. 22-44.
11. Mazurek-Czarnecka, A., Rosiek, K., Salamaga, M., Wąsowicz, K., Żaba-Nieroda, R. (2022). Study on support mechanisms for renewable energy sources in Poland. *Energies, vol. 15, no. 12,* p. 4196.

12. Mikulski, Z. (1998). *Gospodarka wodna*. PWN.
13. Niekurzak, M. (2021). The potential of using renewable energy sources in poland taking into account the economic and ecological conditions. *Energies, vol. 14, no. 22*, p. 7525.
14. Piekut, M (2021). The consumption of renewable energy sources (res) by the european union households between 2004 and 2019. *Energies, vol. 14, no. 17,* p. 5560.
15. Rakowska, J., Ozimek, I. (2021). Renewable energy attitudes and behaviour of local governments in Poland. *Energies, vol. 14, no. 10,* p. 2765.
16. Raport: Polska energetyka wiatrowa 4.0 (2022).
17. Raport: Rynek fotowoltaiki w Polsce 2022 (2022).
18. Raport: Transformacja energrtyczna w Polsce. Edycja 2022 (2022).
19. Seroka, A. (2022). Odnawialne źródła energii jako element zarządzania bezpieczeństwem panstwa. *Zeszyty Naukowe Politechniki Częstochowskiej. Zarządzanie, no. 46,* p. 88.
20. Serowaniec, M. (2021). Sustainable development policy and renewable energy in Poland. *Energies, vol. 14, no. 8,* p. 2244.
21. Shahzad, U., Radulescu, M., Rahim, S., Isik, C., Yousaf, Z., Ionescu, S.A. (2021). Do environment-related policy instruments and technologies facilitate renewable energy generation? exploring the contextual evidence from developed economies. *Energies, vol. 14, no. 3,* p. 690.
22. Śleszyński, P., Nowak, M., Brelik, A., Mickiewicz, B., Oleszczyk, N. (2021). Planning and settlement conditions for the development of renewable energy sources in Poland: Conclusions for local and regional policy. *Energies, vol. 14, no. 7,* p. 1935.
23. Sobocińska, M. (2022). Processes of modernization of consumption in poland in the context of the sustainable consumption and the functioning of the renewable energy market. *Energies, vol. 15, no. 1,* p. 289.
24. Szyba, M. (2021). *Spatial planning and the development of renewable energy sources in Poland.* Acta Innovations.
25. Tutak, M., Brodny, J. (2022). Renewable energy consumption in economic sectors in the eu-27. the impact on economics, environment and conventional energy sources a 20-year perspective. *Journal of Cleaner Production, vol. 345,* p. 131076.
26. Ulewicz, R., Siwiec, D., Pacana, A., Tutak, M., Brodny, J. (2021). Multi-criteria method for the selection of renewable energy sources in the polish industrial sector. *Energies, vol. 14, no. 9,* p. 2386.
27. Ullah, K., Hafeez, G., Khan, I., Jan, S., Javaid, N. (2021). A multi-objective energy optimization in smart grid with high penetration of renewable energy sources. *Applied Energy, vol. 299,* p. 117104.
28. Włodarczyk, B., Firoiu, D., Ionescu, G.H., Ghiocel, F., Szturo, M., Markowski, L. (2021). Assessing the sustainable development and renewable energy sources relationship in eu countries. *Energies, vol. 14, no. 8,* p. 2323.
29. Woźniak, M., Badora, A., Kud, K., Woźniak, L. (2021). Renewable energy sources as the future of the energy sector and climate in poland—truth or myth in the opinion of the society. *Energies, vol. 15, no. 1,* p. 45.

30. Wysocki, A.M. (2022). *Analysis of the auction scheme of support for renewable energy sources in Poland*. Ph.D. dissertation, Instytut Elektroenergetyki.
31. Yikun, Z., Gul, A., Saleem, S., Shabbir, M.S., Bilal, K., Abbasi, H.M. (2021). The relationship between renewable energy sources and sustainable economic growth: evidence from saarc countries. *Environmental Science and Pollution Research, vol. 28, no. 25,* pp. 33390-33399.