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Reviewing the Situation and Prospects for Developing Small Renewable Energy Systems in Poland

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Abstract: The objective of this study was to evaluate changes in the number of small renewable energy sources (RES) power plants and the volume of generated energy in the years 2016–2020, with an outlook to year 2025. The study covered the area of Poland, including the division into provinces and different sources of renewable energy. Absolute values of electric power production and sale were presented, in addition to calculated structure indices. Moreover, the number and structure of small power plants using different renewable energy sources was determined for every Polish province. A classification of the provinces was made, where four classes were distinguished depending on the number of RES plants operating in the provinces. The research results allowed us to diagnose the current situation and make a prognosis for the future, which may translate into support for the development of particular types of installations, depending on the natural and economic characteristics of each area. The added value of the study stems from the fact that previous reports focused mainly on micro or large power plants and the time span covered data before and during the pandemic. This made it possible to assess the impact of the pandemic on the development of small renewable energy sources.

Keywords: small renewable energy sources power plants; development; production volume; prospects post-COVID

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1. Introduction

The COVID-19 pandemic has affected many areas, such as trade, services and industries, causing changes in power demand patterns. The sudden reduction in many areas of social life has raised the uncertainty about the magnitude of power demand [1–3]. The behavior of any economic system can be studied in many variations; no relevant forecast should be neglected and other additional variables can be integrated into a model [2,4,5]. One of the consequences of the pandemic, which only became particularly acute later on, was the high level of inflation. This was partly due to dynamic price increases, including those of fuel [5–8]. The pandemic has affected global supply chains. As the IEA argues, the anticipated impact on the Renewable Energy Sources (RES) industry was primarily related to delays in investment, state-imposed restrictions and social distance guidelines, as well as emerging financial challenges. The launch of component production in Europe was also an important factor in the smooth passage through the pandemic. Plants offering local PV modules, inverters or wind turbines were established in Poland, Germany and the Czech Republic. Consequently, despite concerns, the pandemic did not significantly affect the level of RES development. The majority of experts (67%) at the National Economic Institute, Poland, claimed that the pandemic will accelerate attaining the set goal, while only 14% believed that it will delay it [9]. At the same time, the share of respondents who consider an increase in the share of clean energy important for Poland's development has risen from 91% to 95% [9]. Mędrzycki [10], in line with Szyrski [11], emphasizes that the objectives of energy-related regulation are multifaceted, including the goal to create conditions for sustainable national development. He highlights the fact that the large-scale use of renewable energy sources is no longer merely an object of technological interest, but has become a necessity related to public safety as one of the elements essential for survival in situations of crisis. Thus, it seems crucial to track and identify opportunities for RES development during difficult-to-predict changes in the economy caused, for example, by a pandemic. Small renewable energy power plants benefit from preferential treatment when dealing with the administrative paperwork involved in their launching (e.g., easier connection to the grid, no need to draw up concession contracts). Nonetheless, such installations still represent a small percentage of the structure of all RES producers. As of the end of 2020, the total installed electrical capacity of all RES facilities in the electric power system in Poland was just 10 GW, of which slightly over 183 MW was generated in small RES power plants [12]. According to the Energy Market Information Centre in Poland, the increase in the share of electricity generated from RES was 0.8% annually over the three years from 2019 to 2021, and reached 13.6%.

Until the year 2021, small power plants had been classified [13] as installations with a total electric power capacity of more than 50 kW and less than 500 kW, connected to a power grid with rated power not exceeding 110 kW, or with achievable thermal power in cogeneration higher than 150 kW but not exceeding 900 kW, where the total installed electric power was greater than 50 kW but less than 500 kW (Table 1). Power plants with such capacity are the object of our study.

Table 1. Types of installations depending on the size of the installed power capacity according to Polish legislation.

Types of Installations	Until 30 October 2021	After 30 October 2021
Micro	up to 50 kW	up to 50 kW
Small	50–500 kW	50–1000 kW
Big	above 500 kW	above 1 MW

Source: the authors, based on the Act of 20 February 2015 on Renewable Energy Sources (i.e., Dz. U. z 2023 r. poz. 1436).

Since 2 November 2021, following the amendment of the Act on Renewable Energy Sources of 20 February 2015 (i.e., Dz. U. z 2023 r. poz. 1436), small renewable energy power plants have been defined as those with an installed power capacity of more than 50 kW but not exceeding 1 MW. The purpose of this modification was to stimulate the development of power plants in this sector as the concession obligations of entrepreneurs generating electricity in small RES power plants were eased. Additionally, power plants with a capacity of up to 500 kW were exempted from the obligation to feature such documents as the Study of Conditions and Directions of Spatial Development and the Local Spatial Development Plans. Previously, such an exemption had applied only to power plants with a capacity of up to 100 kW. In turn, this threshold was raised to 1 MW for ground photovoltaic plants built on fifth- and sixth-class land and wastelands [14]. It is noteworthy that all rooftop photovoltaic installations were exempted from the aforementioned capacity limits.

However, some questions arise; namely, how rapidly is the small RES power plant segment developing, and which energy sources dominate in the electric power generation in Poland and in each Polish province?

The objective of this study was to evaluate changes in the number of small renewable energy power plants and their power production volume in the years 2016–2020 with an outlook to the year 2025. It needs to be added that due to changes in the law, this outlook pertains only to power plants with a capacity up to 50 kW.

2. Literature Review

2.1. Reasons for Increasing the Use of Renewable Energy Sources

More than 78% of the EU's greenhouse gas emissions come from energy production and use. Decarbonizing the EU's energy system is therefore key to achieving climate goals and for the EU's long-term strategy to become carbon neutral by 2050 [15,16]. In this regard, global and EU climate policy sets the direction for many other policies, especially energy policy. The EU adopted and implemented the concept of climate policy in 1993 by ratifying the Climate Convention [17]. In the first half of November 2021, the UN Climate Summit COP26 [18] in Glasgow, Scotland, held an important Earth Summit for the future of our planet. Slightly earlier, i.e., at the G20 summit preceding the Glasgow climate summit, the CO_2 reduction target from the 2015 Paris Agreement was confirmed. The European Green Deal also focuses on three main goals for the clean energy transition that will help to reduce greenhouse gas emissions and improve quality of life. These goals are to ensure an affordable and secure energy supply in the EU, to create a fully integrated, interconnected and digital EU energy market, and to prioritize energy efficiency, improve the energy performance of buildings and develop an energy sector based mainly on renewable sources [19,20]. The transition to a low-emission economy is a process that includes changes at three interrelated levels: economic conditions (the development of energy-saving solutions and renewable energy technologies (RES)), the promotion of material-saving production and industrial processes, environmental protection and energy security. Environmental education, both professional and social, and shaping appropriate consumer attitudes are all important. The above-mentioned elements constitute a framework for ensuring the economic, energy and ecological security of a country and form the background for sustainable and lasting development [21–23]. Bridge et al. [24] studied energy transition as a geographical process, including the reconfiguration of current patterns and the scale of economic and social activity. Rifkin [25] predicts that the third industrial revolution involves much more than just a change in the energy regime. The new system will also entail completely new business models. Widely available renewable energy will enable thousands of distributed companies and business partnerships (small renewables) to operate in collective networks that function more like ecosystems than economic markets. The author emphasizes that civilization based on fossil fuels will probably collapse around 2028. Global and regional trends indicate that energy demand will soon be met by the widespread use of renewable energy sources. However, energy sources driven by weather and climate are characterized by significant spatial and temporal variability. One of the commonly mentioned solutions to overcome the mismatch between demand and supply provided by renewable generation is the hybridization of two or more energy sources in one power plant (e.g., wind–solar, solar–hydro or solar–wind–hydro) [26,27]. Of all the renewable energy sources, solar and wind energy have proven to be the most promising owing to their high resource potential, technological maturity and economic viability. This is evidenced by their growing share in global electricity production. However, solar and wind energy resources are highly variable on spatial and temporal scales. This creates many challenges related to their integration with a network [28–30]. Additional mitigation measures are required to increase system flexibility so that sudden imbalances resulting from the combined effects of renewable energy generation and demand can be addressed [31]. Energy systems based on variable renewable energy (VRE), such as solar energy (PV, PV/T) and wind energy (wind turbine), are intermittent due to weather and climate conditions. This poses a management challenge to achieve a stable energy supply. VRE-based microgrids must take this variability into account, for example, by using energy storage devices. Another adaptation option is to employ standby generators or constant power sources working with VRE [32].

There is no doubt that building a low-emission and resource-efficient economy whose priority is environmental protection in the face of the depletion of conventional energy sources is desirable [33–38]. Researchers indicate that the production of renewable energy helps reduce a country's energy dependence [39–41]. This aspect is of strategic importance for many world economies, also due to the Russian–Ukrainian war (read more [42–44]). Many researchers have analyzed the issue of using renewable energy sources both in Poland [45–47] and the European Union [44,48–50].

The share of renewable energy sources in gross final energy consumption indicates that Sweden was a clear leader in the European Union in 2021 (nearly 63%). In Finland

and Lithuania, this share was over 40%. However, it is the countries outside the European Union that fare the most favorably: Iceland (80%) and Norway (approximately 75%) [49]. In Poland, this share was 15.6% (with the European Union average being 21.8%). From 2004 to 2018, Poland doubled its share, but in each year it achieved a result below the average in the European Union. Poland is expected to reach 23% by 2030, and 28.5% by 2040. Renewable energy sources are a way to achieve this goal [51].

2.2. Potential of Primary Renewable Energy Sources

The most common renewable energy sources include wind energy, water energy, solar energy, biogas and biomass.

Wind energy is one of the basic renewable energy sources. Its share in the total electricity generated from renewable sources in 2021 was 37.5% [51,52]. The most favorable conditions enabling the effective use of electricity exist on the coasts of the Atlantic Ocean, the Baltic Sea and the North Sea [53]. The conditions for the development of wind energy are limited by geographical conditions [54,55], and wind energy itself is closely related to the landscape. Wind farms can be seen from many kilometers away, which reflects their size and color [54]. The local community often does not agree to the location of wind turbines in their neighborhood, pointing to their negative consequences [56,57]. See more [58–60].

The study revealed that both the NIMBY syndrome and the lack of civic engagement influence attitudes towards renewable energy technologies in rural areas. The NIMBY ("not in my backyard") term describes negative public attitudes towards proposed development projects [56]. In Greece, on the other hand, since 2009 investors have pursued an anarchic policy of submitting large numbers of applications for the construction of renewable energy production projects. There have been applications made and licenses granted without any strategic design, usually of a very large size on relatively small territories on islands, often violating several environmental or cultural restrictions set out in the relevant legislation [61]. The article proposed an original, optimized multicriteria wind energy development model for the studied region, exploring various types of technologies that may appear in the system, taking into account recent legal and political changes in the field of renewable energy regulation in Poland. The results of the optimization model show that the currently binding Act on Investments in Wind Farms in Poland actually halted the development of wind energy in the region. On the other hand, in accordance with the objectives of the adopted draft of the Polish energy policy until 2040, it is expected that the share of renewable energy in electricity production will increase in 2030 in the studied region. Therefore, the paper argues that policy changes are necessary to meet the renewable energy goals of Poland [53]. In Romania, a change in legislation in 2013 that reduced support for RES producers led to a significant reduction in investments in this area, and may eventually result in their termination [59].

Hydropower in 2021 accounted for 32.1% of the total electricity generated from renewable sources [49]. Although energy derived in this way cannot meet the total demand for electricity, it is an opportunity for parts of the world most in need of clean energy [59]. A total of 70% of the economically viable potential hydropower resources remains to be tapped, and modern hydropower plants provide more than 90 energy conversion processes [62,63]. Many researchers have written about the potential of hydropower [64–68]. In various environmental conditions, there are examples of the combined operation of a wind-pumped power plant with a concentrating solar power plant for island systems. To achieve a higher share of renewable energy in energy production, a special design of such facilities is required to comply with local restrictions. It is also important for a facility to achieve significant energy savings during peak periods [61].

Solar energy in 2021 accounted for 15.1% of the electricity generated from renewable sources [51]. Studies have shown that solar energy can meet global energy demand [69]. Photovoltaic technologies are developing at an astounding pace. They are increasing their efficiency while reducing costs and increasing the area of operation [70]. Due to electricity consumption, the payback period required for an installation may be from 5 to 6 years [71].

There are also examples of hybrid power facilities producing thermal energy for heating devices. Such systems consist of collectors placed with a selective coating, water tanks as the means for thermal energy storage and a biomass heater. Beyond any technical aspect, it certainly demonstrates the feasibility of 100% heating loads coverage in buildings based on RES (solar radiation and biomass), especially in southern European climates. The payback period of the required investments is low, even less than 5 years [72].

Many researchers have analyzed the development and efficiency of photovoltaic technologies [73,74]. For example, energy storage is very important. A comparison of the results showed that the instantaneous step size P&O algorithm is better and provides more stable energy to the load without fluctuation than the instantaneous step size INC algorithm, and it is also better than the standard P&O and INC algorithms.

The controlled and corrected energy from the storage system to the load is presented during the working photovoltaic array under varying solar irradiation. The SOC characteristics of the supercapacitor and battery have been illustrated to demonstrate the effectiveness of the controller. The simulation results proved the importance of the battery and the supercapacitor used for the photovoltaic array under different values of solar irradiation and proved the effectiveness of the proposed control and energy optimization management strategy. For high and low irradiance levels, the efficiency of the transformed energy from the photovoltaic array was more than 99% [75].

Other researchers have focused on the feasibility of applying solar energy to various industries [74–77], or have emphasized the special importance of solar energy in meeting the global energy demand in a sustainable manner [78–82].

Biofuels in 2021 accounted for 7.4% of total electricity generated from renewable sources [49]. Biogas is produced from biomass [83]. The amount of biomass with significant energy potential produced by society is increasing worldwide [84]. Biogas is a competitive and cost-effective source of energy [85]. It has many applications and is an effective solution to the global economic crisis [86]. Many studies have investigated the potential of biogas and biomass as renewable energy sources [78,79,87–89]. Energy production from biogas is particularly important in countries where agriculture is the primary form of production; India is an example. However, biogas can be used all over the world. Generating electricity from biogas has become a major trend in many countries, such as Germany, China and India [90–92]. A review of the global research progress in the past 10 years shows an increase of ~90% in the biogas industry (120 GW in 2019 compared to 65 GW in 2010). In 2017, Europe contributed over 70% of the world's biogas generation, representing 64 TWh. Finally, the different regulations that manage the biogas market have been presented [87].

Thus, there is great potential in renewable energy sources, which will allow the world's economies to significantly reduce and, in the long term, even abandon non-renewable energy sources, which will have a positive impact on the environment, as well as on countries' energy independence.

2.3. The Impact of the COVID-19 Pandemic on the Development of Renewable Energy Sources

The COVID-19 pandemic has had an impact on the widespread use of modern technology. In particular, a dramatic shift in the use of digital technologies has been identified that will affect all aspects of work and life. How this change plays out remains largely dependent on our reactions to emerging trends and how they will be shaped [16,93]. The energy sector is one industry that also stands to gain significantly from the deployment of Artificial Intelligence [94,95] following the pandemic crisis. For example, among the methods used to make weather forecasts are critical neural networks, with which it is possible to foresee, for example, insolation over a longer period of time [96]. Louzazni et al. [97] presented a monthly forecast of energy generated from photovoltaic modules installed in a hot area in Egypt's Nile Delta. Their article deals with a set based on an adaptive solution for forecasting the production of photovoltaic (PV) systems with 1-day access [98]. Another example is the use of an artificial neural network (ANN) which employs up to 10 different learning algorithms (i.e., fundamentally different algorithms). The internal parameters of the ANN were designed to efficiently map inputs to outputs with 23 different cargo datasets (i.e., different weather combinations when available) [99,100].

Furthermore, there are views in the literature that RES development is a response to the economic downturn caused by the COVID-19 pandemic, as many countries have implemented policies that encourage investment in renewable energy and digital energy systems [18]. A comprehensive and analytical review of the impact of COVID-19 on the energy sector and the role of artificial intelligence (AI) in mitigating its effects is presented in Arsad et al. [101].

It is worth recalling, however, that initially the coronavirus outbreak in China led to commodity shortages and a delay in the supply of components necessary for modernization or construction processes in the renewable energy sector as in other sectors, even before the announcement of an emergency state in other parts of the world. This is because there was an overshooting of supply chains. The economic deconstruction entailed a struggle with the effects of the economic crisis during and after the pandemic [102,103], including the issuing of new regulations. In many countries, legislators focused on countering the effects of forced changes in investment schedules. The reason for this was the timeliness of their implementation, which directly affected the ability of energy producers to benefit from renewable energy support schemes [104,105].

Studies [106,107] indicated that the right policies can turn the risks of pandemic uncertainty into huge opportunities for renewable energy markets, and ultimately investors not only think about hedging the oil-price risk, but can further benefit from portfolio diversification by investing in renewable energy. For example, during the Ebola virus outbreak in West Africa (2013–2016), many predicted economic impacts did not materialize due to the dramatic drop in energy production during that period. According to the World Development Report (2019), in 2015 bauxite, iron ore and gold prices fell by 30–60% compared to the previous years in countries, such as Guinea, Liberia and Sierra Leone, which were affected by the Ebola virus, and the reason for this was the diminishing marginal returns in the energy industry. Likewise, looking back to 2003 shows much uncertainty related to the outbreak of SARS. There was only a slight 1% increase in China's annual jet fuel consumption compared to the previous year, when consumption increased by more than 28%, according to International Energy Agency (IEA) data. Due to the huge impact of COVID-19, the IEA suggests that investment in renewable energy has been more resilient than fossil fuels, but final investment decisions in the first quarter of 2020 for new utility-scale wind and solar projects fell to levels seen three years before. Electricity demand fell by 20% or more during periods of full blockade in several countries, equivalent to an estimated 5 bcm of lost gas consumption.

While the literature has examined how pandemic uncertainty has driven oil and stock markets to historic lows, the study of the consequences of uncertainty for renewable energy (RE) as the world's fastest growing primary energy source is still a work in progress, preventing a comprehensive insight into the consequences of pandemic uncertainty for future energy paths. Moreover, the correlation between the prices of several commodity markets and the RE index has continued uninterrupted [108].

3. Materials and Methods

Since 2016, the Energy Regulatory Office in Poland [12], which is responsible for regulating the electric power market in Poland, has been issuing aggregated reports including data about the generation of electricity from RES, namely, by small renewable energy power plants. As mentioned, until 30 October 2021, small RES power plants had been defined as those with a total electric power capacity of over 50 kW but below 500 kW. Afterwards, the definition was modified, expanding the range of small power plants as the maximum power installed was increased to no more than 1 MW. Consequently, it would be unreliable to compare the data on small installations from the 2021 report with the data from previous years (2016–2020). Thus, our analysis comprised the data from 2016 to 2020. Different examples of power producers are given in Table 1. It should be underlined that one producer can have the same type of a small RES power plant in one province in different localities, the same type of small RES power plants in several provinces, or different types of small RES power plants in different provinces. The analysis of data from every province focused on the number of particular types of small RES installations and not on energy producers (Table 2).

Table 2. Fragment of the report's summary information on electricity generation from renewable energy sources in a small installation (as of 31 December 2020) [105].

Name of Producer	Location (Province, Locality)	Type of Power Plant
Inter Energia S.A	śląskie; Pyskowice Zaolszany śląskie; Racibórz	biogas biogas
MEWAT Sp. z o.o.	pomorskie; Zapora kujawsko-pomorskie; Łochowo	hydropower hydropower
Mała Elektrownia Wodna Nowy Młyn S.C. W. Kotarska, L. Kotarski	warmińsko-mazurskie; Nowy Młyn podlaskie; Blenda	hydropower solar radiation [1]

[1] Source: the authors, based on [109].

Absolute values of electric power production and sales from small RES installations in Poland, including the division into different sources of energy, were presented, and the structure indices were calculated from these data. Moreover, the number and structure of small RES installations in every province were given.

The Polish provinces were divided into 4 classes depending on the number of small renewable energy power plants [9,110]:

1. Provinces with a high number of small RES power plants: $di \geq \left(\overline{di}\right) + Sdi$;
2. Provinces with a moderate number: $\left(\overline{di}\right) \leq di < \left(\overline{di}\right) + Sdi$;
3. Provinces with an average number: $(\overline{di}) - Sdi \leq di < (\overline{di})$;
4. Provinces with a low number: $di < (\overline{di}) - Sdi$

where:
di—number of installations in a province;
$(\overline{di})$—arithmetic mean of the number of installations in a province;
Sdi—standard deviation of the number of installations in a province.

The maps illustrate the division into classes taking into account the different types of RES separately, marked with symbols, while the colors denote the general class of each province.

An additional part of the research consisted of a forecast made with a logistic function. Continuation of the current situation is most probable within the horizon of predictability [111]. Thus, the logistic function applied in the study was the one used for modelling various processes of growth (cf. [112]). For practical application of this function, it was modified by entering three time-constant parameters determining the course of the function (a, b and c) [113]:

$$\mathrm{x} = \frac{\mathrm{a}}{1 + \mathrm{b}\exp(-\mathrm{tc})};\ \text{where}:\ \mathrm{a},\ \mathrm{b},\ \mathrm{c}\ \geq\ 0,$$

where:
a—the saturation of the investigated phenomenon determined heuristically;
b, c—the function's parameters chosen through statistical estimation.

In order for the logistic function to be used for forecasting economic phenomena and processes, the value of parameters a, b and c must be matched to historical data, with the shortest time series having at least three elements in order to obtain reliable results, but the longer the time series, the better the estimation, as a result of the smaller influence of random errors [113].

In the study conducted, parameter a, which determines the natural saturation level, was assumed to be 1600, which is 4 times the number of installations in the initial study period. On the basis of data from 2016 to 2020, using a STATISTICA 13.1 statistical and analytical software package, parameters b and c of the logistic function were calculated and, based on them, graphs were created for the total number of small-scale RES installations and their type. Based on the data from years 2016–2020, and using the software package STATISTICA for data statistics and analysis, parameters of the logistic function were calculated, and these served to plot a diagram for the total number of small RES power plants along with the number of each type. The application of the logistic function enabled us to identify development trends until 2050 according to the time series. To complete the assessment over time, absolute differences in energy production from small RESs were counted, also known as absolute difference increments. They are measured by how much the dependent variable changed between periods (in this case consecutive years). The independent variable was time.

4. Results

Renewable energy sources are an alternative to fossil fuels, and can contribute to the reduction in emissions of greenhouse gases [56,114,115]. It is expected that 40% of the energy consumed in the European Union will originate from renewable sources by the year 2030 [116–118]. Over the analyzed time period (2016–2020), a systematic growth in the generation of electric power from small RES power plants was observed, going from 122.1 GWh in 2016 to 342.7 GWh in 2019, alongside an increase in the amount of electricity sold which has been produced using RES to the obligated seller, going from 89.73 GWh in 2016 to 238.33 GWh in 2019. However, in 2020 both the generation and sale of such electric power slightly declined relative to the previous year (Figure 1).

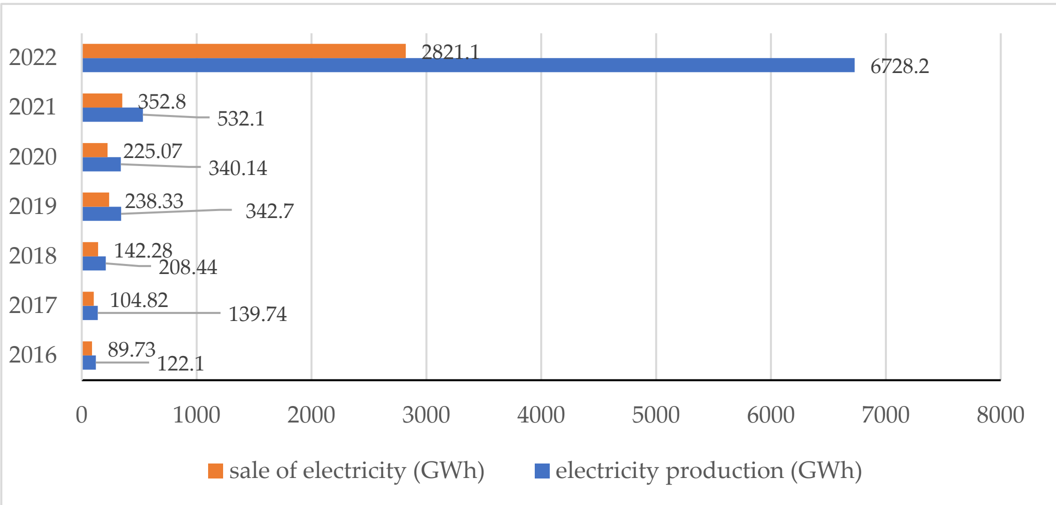

Figure 1. Production and sale of electricity generated in small RES power plants in 2016–2020. Source: the authors, based on [109].

The increase in the generation of electricity in small RES power plants was stimulated by an overall increase in the share of renewable energy sources in all the sources used for generation of electricity in Poland. Proportionally to the increase in the electric power generation by small RES installations, the amount of electricity sold to the obligated seller increased. The figure also shows production and sales in 2021 and 2022. The large increase was mainly due to a change in the law regarding the upper limit of the range of the total installed electric capacity of RES installations subject to registration in the RMIOZE (from 0.5 MW to 1 MW). Therefore, the years 2021–2022 were excluded from further study.

Most electricity generated using small RES installations and sales originated from small hydropower plants (hydropower) (Figures 2 and 3); however, despite the year-to-year increase in the volume of production expressed in GWh, the share of hydropower decreased every year—from 75% in 2016 and 2017 down to 43% in 2020. Generally, the biggest type of RES in Poland for years has been wind energy. Biomass power plants were omitted due to their marginal share.

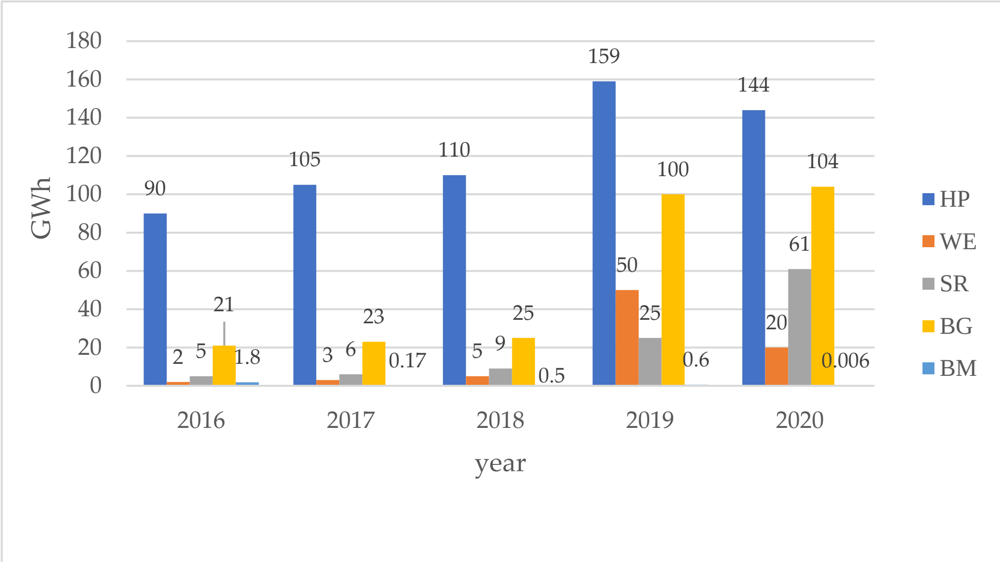

Figure 2. Production of energy in small RES installations in 2016–2020, including the division into types of sources (GWh), HP—hydropower, WE—wind energy, SR—solar radiation, BG—biogas (non-agricultural), BM—biomass (not visible on the graph). Source: the authors, based on [109].

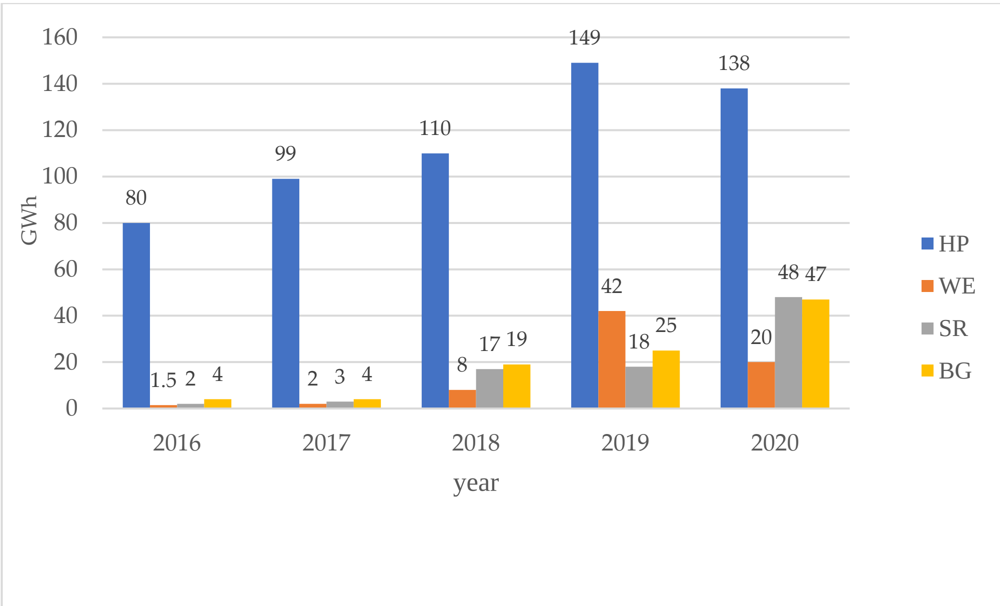

Figure 3. Sale of energy in small RES installations in 2016–2020, including the division into types of sources (GWh), HP—hydropower, WE—wind energy, SR—solar radiation, BG—biogas (non-agricultural), BM—biomass. (Biomass, due to its share of approximately 0.002%, was not included.) Source: the authors, based on [109].

The second biggest RES installations generating electricity were biogas plants using biogas other than from agriculture, producing nearly 24 GWh in 2016 and increasing to 107.68 GWh in 2020. The share of this source grew from slightly less than 20% to nearly 32%. The year 2019 is noteworthy, as there was a much higher electric power generation from wind farms than in the other years. Over the entire analyzed period, the lowest share was made up by energy generation from biomass, which did not exceed 0.5% in any of the years.

The reason for the decrease in the share of small hydropower plants in the production of electricity by all RES installations can be found in numerous protests aiming to reduce this type of electric power production. According to the WWF manifesto: hydropower is not 'green' energy. 'Green' hydropower is a myth, and it has ceased to be profitable. As the contribution of small hydropower plants has fallen, the share of electric power generated from other sources, mainly biogas plants, has risen. In 2016, 73% of electricity produced in small RES installations was sold, while in the year 2020 this was 66%. The relation between the volume of electricity produced in the analyzed time period versus its sale was identical—most electricity sold originated from small hydropower plants, with 81.43 GWh sold in 2016, 147.95 GWh in 2019 and 134.72 GWh in 2020 (Figures 4 and 5).

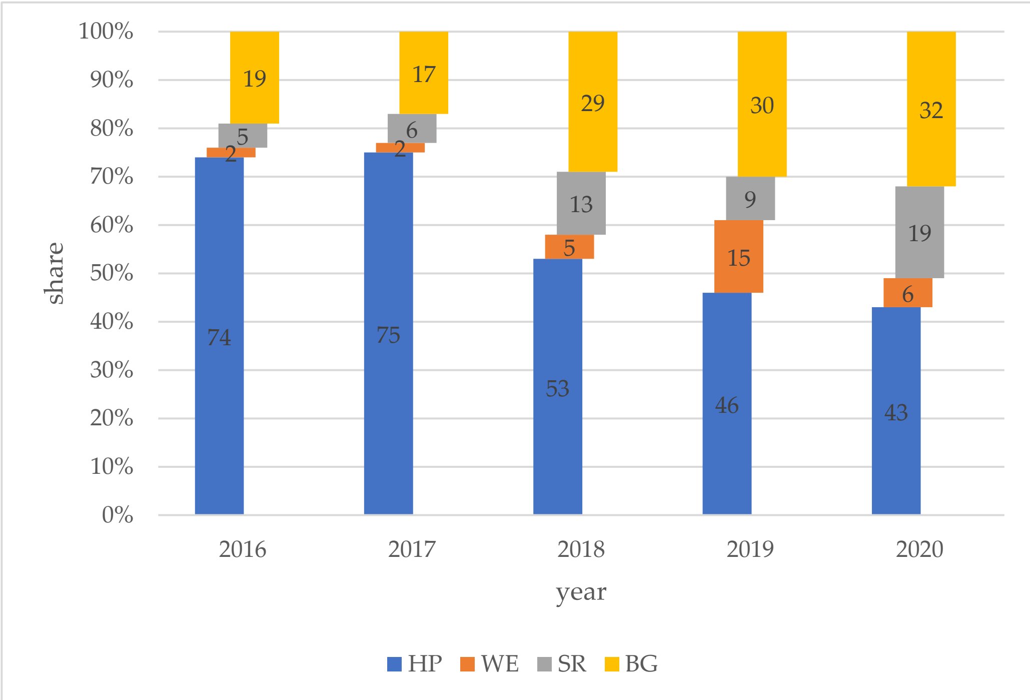

Figure 4. Share of electricity production small RES power plants in 2016–2020, with the division into types of sources (in GWh). Source: the authors, based on [109].

Hydropower plants continued to produce the most energy in 2021, but photovoltaic plants produced the most energy in 2022. This significantly changed the structure of RES production (Figure 6).

More than 90% of the electricity produced in small hydropower plants was sold each year. However, the amount of actual production sold varied from year to year depending on the type of source (Figure 7). This means that the differences in the share of sales were not only due to an increase in the production of sources gaining increasing popularity (photovoltaics), but also a decrease in the production of, for example, energy from non-agricultural biogas.

In the analyzed time period, a relatively large increase in the number of small RES installations in total (Figure 8) and divided into types of energy sources was observed. When the year 2016 is taken as the starting point (100%), the number of small RES installations nearly doubled (increase of 91%). The rise in the number of installations progressed steadily over the whole analyzed period of time.

The rise in the number of small installations using different types of RES was varied. Over the five years submitted to analysis, the increase in hydropower plants was small (increasing by 11% relative to year 2016). As for the other sources of renewable energy, the increase was more spectacular—the number of installations using solar power increased by 319%, those using wind power by 209%, and non-agricultural biogas by 160% (Figure 9).

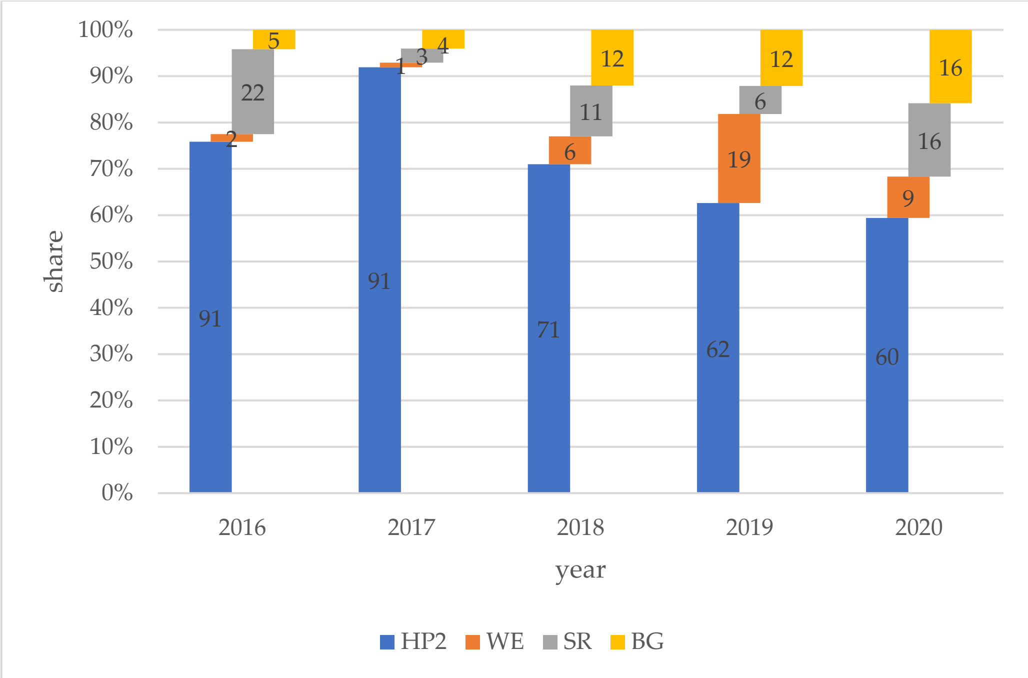

Figure 5. Share of electricity sale from small RES power plants in 2016–2020, with the division into types of sources (in GWh). Source: the authors, based on [109].

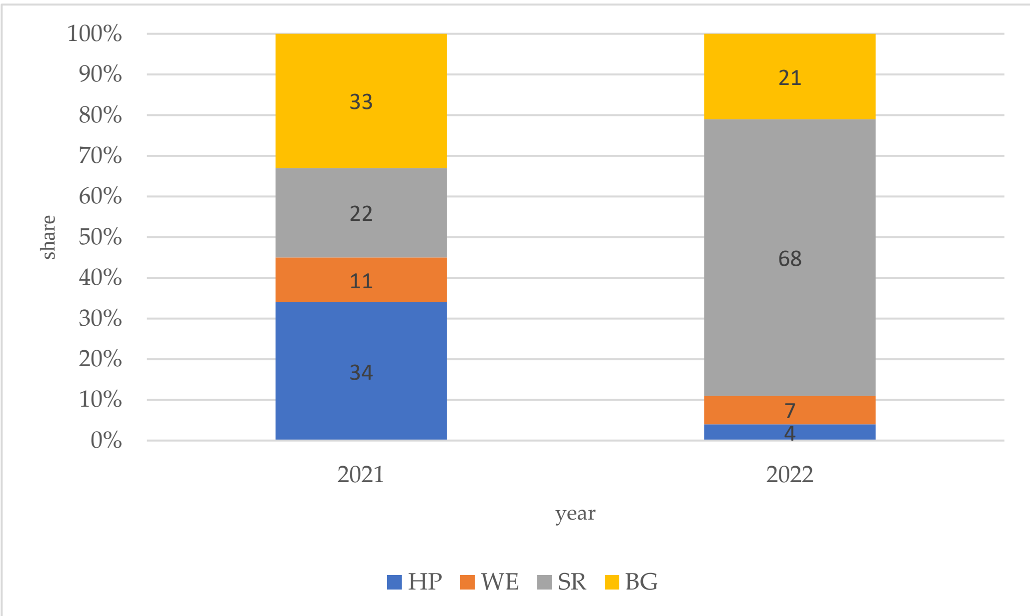

Figure 6. Share of electricity production and sale from small RES power plants in 2021–2022, with the division into types of sources. Source: the authors, based on [109].

If there were any decreases, they were rare and very small, with just 1 installation fewer (between 2019 and 2020 in Dolnośląskie province and between 2016 and 2017 in Lubelskie and Małopolskie provinces). Throughout the whole period, the average number of installations in all the provinces continued to rise, going from 29 in 2016 to 56 in 2020. The lowest number of small RES power plants in 2016–2020 operated in Lubuskie province;

the highest number was in Warmińsko-mazurskie province in 2016, Dolnośląskie province in 2017–2019 and in łódzkie province in 2020. With respect to Polish provinces (Figure 10), an increase in the number of small RES installations was determined in each of the 16 Polish provinces in each consecutive year and compared to the 2016 base year (Figure 11). What is important, however, is how the growth in numbers has evolved in each province. The largest increase in years was recorded in Lubelskie and Podkarpackie, while the smallest increase was in Warmińsko-Mazurskie.

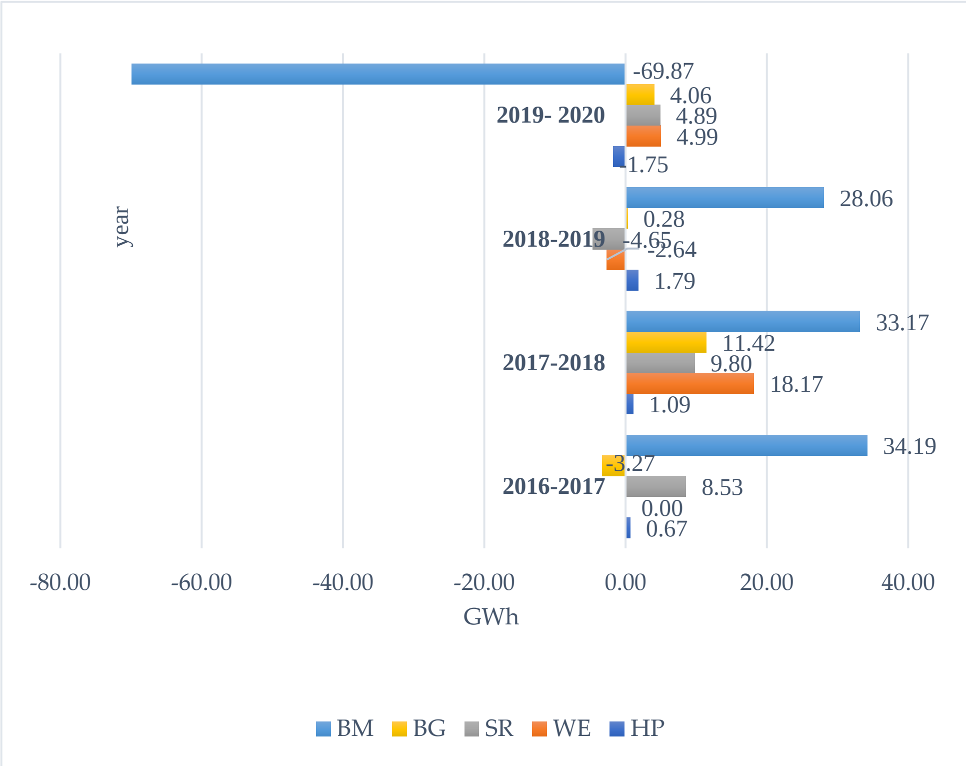

Figure 7. Absolute growth (difference) in sold electricity generated in small RES power plants from 2016 to 2020 by source type, presented year-to-year (in GWh). Source: the authors, based on [109].

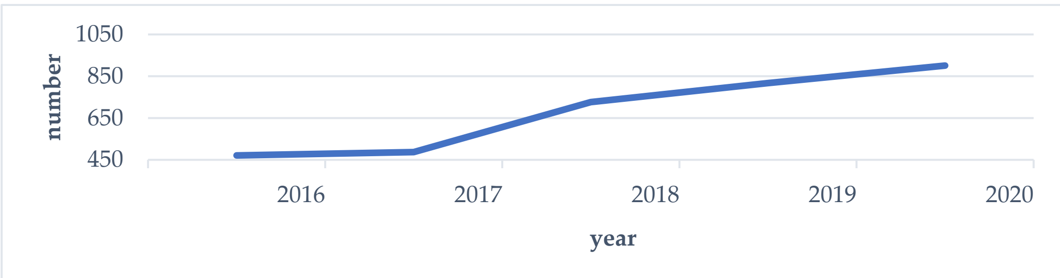

Figure 8. Number of small RES power plants in 2016–2020. Source: the authors, based on [109].

During the whole analyzed period, Dolnośląskie province was leading in the number of small hydropower plants, while Kujawsko-Pomorskie and łódzkie provinces had the highest number of wind-power plants, and śląskie province surpassed the other provinces in the number of power plants using solar power and biogas. The provinces łódzkie (2018–2020), śląskie (2017–2020) and świętokrzyskie (2017) each had only one installation converting biomass to energy.

Between the beginning of the analyzed period (year 2016 = 100%) and its end (year 2020), there were significant changes in the Polish provinces regarding the number of particular types of small RES power plants (Figure 12). There was an increase in every source of small renewable energy plant in nearly all provinces. The following were the exceptions:

- Lubelskie province: a decrease by one in the number of wind-power plants,
- Łódzkie province: a decrease by five in the number of hydropower plants,
- Podkarpackie province: a decrease by one in the number of hydropower plants,
- Śląskie province: a decrease by one in the number of hydropower plants,
- Warmińsko-Mazurskie province: a decrease by two in the number of hydropower plants.

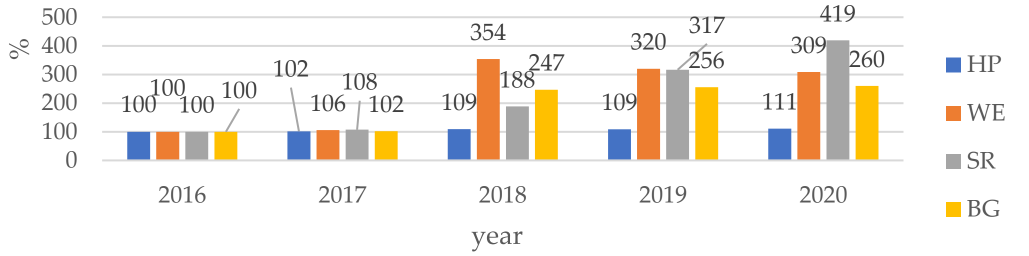

Figure 9. Increase in the share of small RES power plants, with the division into types of sources (year 2016 as the starting point). Source: the authors, based on [109].

Figure 10. The administrative division of Poland into provinces. Source: the authors.

In the years 2016–2020, there were some spectacular increases: there was a 2300% in the number of installations using wind power in Kujawsko-Pomorskie province (from 1 to 23), a 1850% increase in the number of installations using solar power in Lubelskie province (from 2 to 37), and a 1100% increase in the number of installations using solar power in Zachodniopomorskie province (from 3 to 33). The largest increase occurred in the number of power plants using solar power, with an average increase of nearly 500%, while the smallest increase was found in hydropower plants, with an average increase of 8%.

Figure 13 shows maps of Poland illustrating the status of small RES installations in the provinces at the beginning of the analyzed period, i.e., in year 2016, and at its end, i.e., in year 2020.

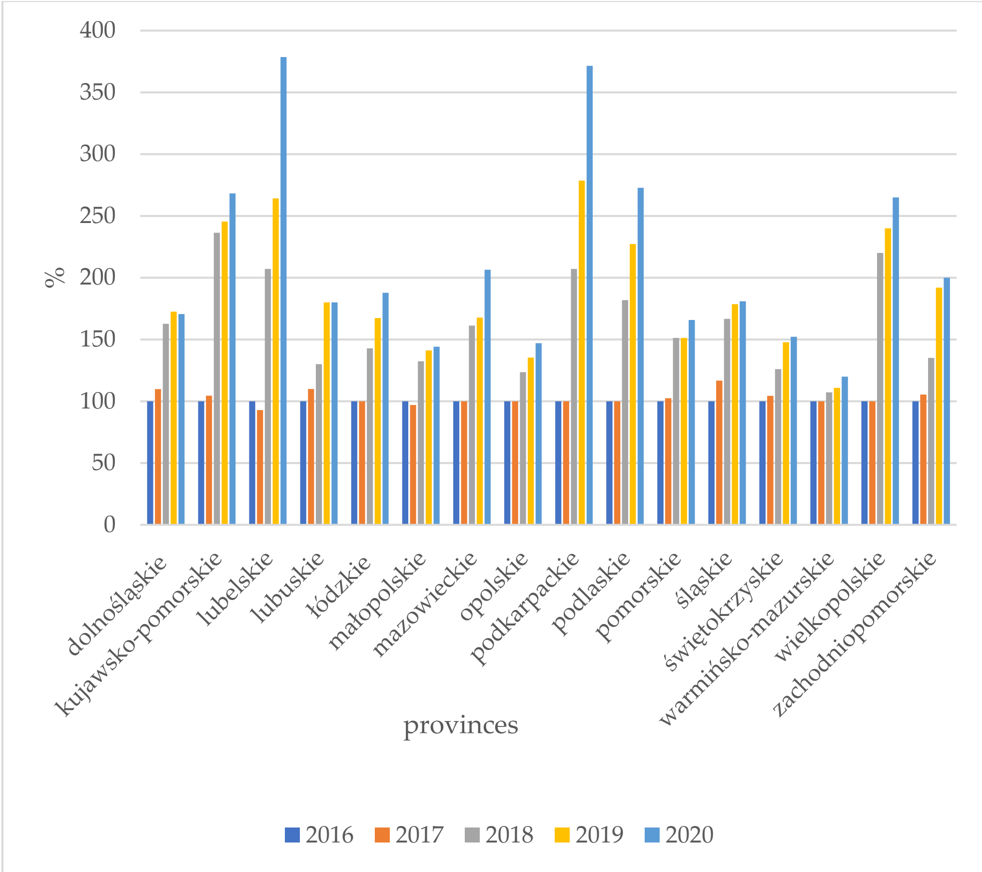

Figure 11. Dynamics of change number of small RES power plants in 2016–2020 in the Polish provinces, Source: the authors, based on [109].

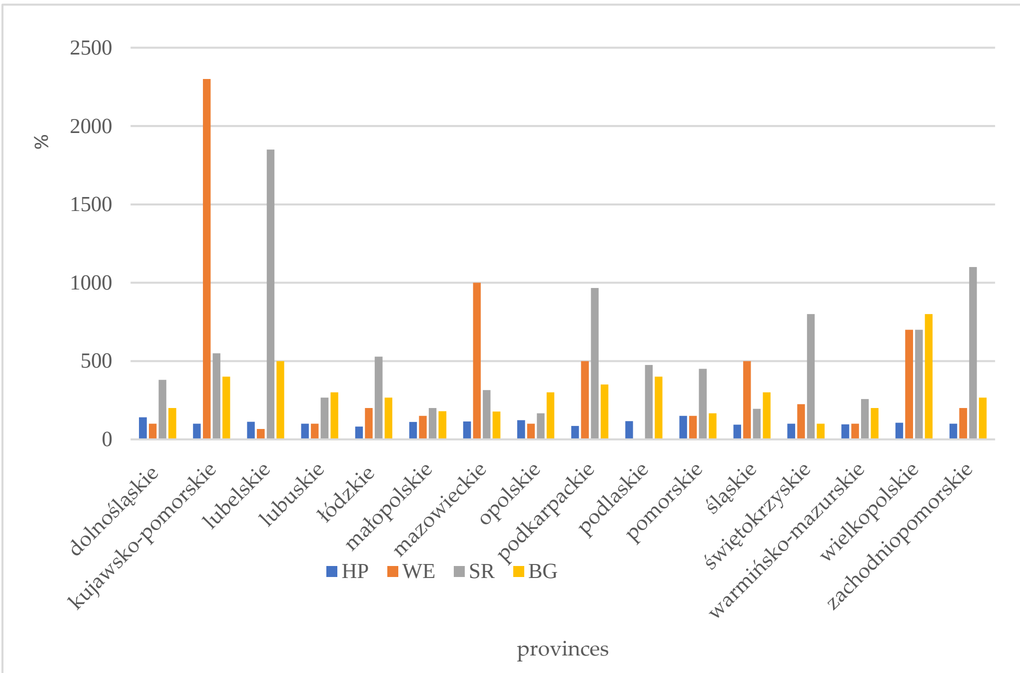

Figure 12. Increase in the share of small RES power plants, with the division into types of sources in the Polish provinces in years 2016–2020 (year 2016 as the starting point). Source: the authors, based on [109].

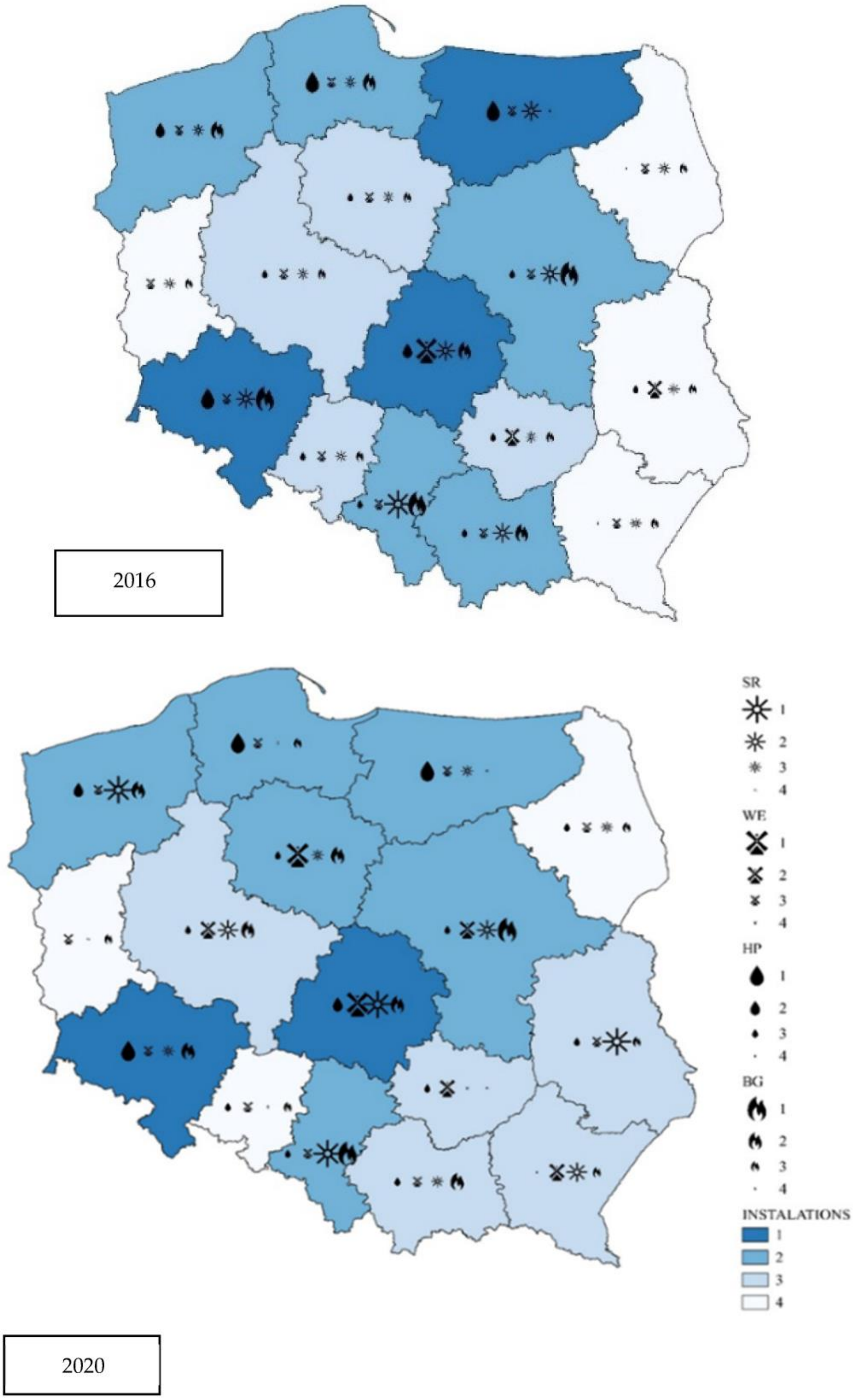

Figure 13. The Polish provinces divided into classes in 2016–2020: 1, provinces with a high number of small RES power plants: $di \geq (\bar{d}i) + Sdi$; 2, provinces with a moderate number: $(\bar{d}i) \leq di < (\bar{d}i) + Sdi$; 3, provinces with an average number: $(\bar{d}i) - Sdi \leq di < (\bar{d}i)$; 4, provinces with a low number: $di < (\bar{d}i) - Sdi$, where *di*—number of installations in a province, $(\bar{d}i)$—arithmetic mean of the number of installations in a province, *Sdi*—standard deviation of the number of installations in a province. Source: the authors.

The nominal number of small RES installations in every province in the years 2016–2020 increased (the record holder was Łódzkie province, with a nearly 90% increase). In 2016, a high number of all types of small RES installations was found in three provinces (class 1): Warmińsko-Mazurskie, Dolnośląskie and Łódzkie. In 2020, Warmińsko-Mazurskie province fell to class 2. The position of two other provinces, Małopolskie and Opolskie, also deteriorated. It improved in only three provinces: Kujawsko-Pomorskie, Lubelskie and Opolskie. The changes were by one class only.

In the analyzed period, the nominal number of hydropower plants decreased in four provinces: Łódzkie, Warmińsko-Mazurskie, Podkarpackie and śląskie. A high number of such installations in both 2016 and 2020 was found in the provinces Dolnośląskie, Pomorskie and Warmińsko-Mazurskie (despite the mentioned decrease in the nominal number of installations). It was only Podlaskie province that advanced from class 4 to 3 in respect of this type of small RES plant. Most of the Polish hydropower facilities are in the Vistula River basin, especially on its right-bank tributaries. Suitable conditions for the construction of small hydropower plants are found in the Carpathian Mountains, the Sudety Mountains and in Roztocze, but also on the rivers in Pomorze. The potential of the Odra River for building hydropower plants is also significant (Potencjał Hydroenergetyczny Polski, online).

The number of small RES installations using wind power decreased only in Lubelskie province. Between the years 2016 and 2020, none of the Polish provinces were classified in the lowest category. Łódzkie province was characterized by a high number of such installations throughout the whole time period. A considerable increase took place in Kujawsko-Pomorskie province (going from class 3 to 1). The Mazowieckie, Podkarpackie and Wielkopolskie provinces improved by one class (from class 3 to class 2). One province, Lubelskie, fell from class 2 to 3.

Current studies [119–122] show that wind-power plants are also located in sites with less than good wind conditions [102–104]. This is made possible by increasingly better technologies. In Poland, the legal regulations permit the location of wind farms only in rural areas and within the perimeter of marine areas.

Another localization theory which gives rise to some implications concerning the siting of wind power facilities is behavioral theory [123,124]. The investor depends on decisions issued by the administrative authorities and the attitude of the local community. The nominal number of small solar power plants in every province over the years 2016–2020 increased. The highest efficiency in our country was achieved by installations in the south of Poland, especially in the provinces Podkarpackie, Małopolskie, Lubelskie, Opolskie and Dolnośląskie. The least energy per kiloWatt-peak was obtained in the provinces situated in the north of Poland, especially in the provinces Zachodniopomorskie, Pomorskie and Warmińsko-Mazurskie (excluding the coastline and the area in the vicinity of Gdańsk). A kiloWatt-peak is a unit showing the maximum capacity of a photovoltaic panel determined for Standard Test Conditions, which is solar radiation of 1000 W/m^2 and an ambient temperature of 25 °C. Thus, an amount of 1000 KWh/KWp means that one photovoltaic panel with a 1 kiloWatt-peak capacity can produce approximately 1000 KWh of electricity.

A high number of installations over the whole analyzed period was found in śląskie province. A considerable increase appeared in two provinces—Lubelskie and Zachodniopomorskie, which advanced from class 3 to class 1 over the 5 years. An improvement by one class took place in the provinces Łódzkie (from class 2 to 1), Podkarpackie and Wielkopolskie (going from class 3 to 2). A decrease by one class took place in the provinces Dolnośląskie, Małopolskie and Warmińsko-Mazurskie (from 2 to 3), as well as in Lubuskie, Opolskie, Pomorskie and świętokrzyskie (from 3 to 4).

Also, the nominal number of small RES power plants using biogas other than agricultural one increased in every province in the years 2016–2020. The provinces Mazowieckie and śląskie were characterized by a high number of such installations throughout the whole time period. 5 provinces moved upwards or downwards by one class: kujawsko-pomorskie and Wielkopolskie (from 3 to 2), Dolnośląskie (from 1 to 2), Pomorskie (from 2 to 3), and świętokrzyskie (from 3 to 4).

Due to the very low numbers of small RES power plants using biomass, these installations are not shown on the maps. In 2016, there were no such plants operating in Poland, while in year 2020 there were only 2, in the provinces łódzkie and śląskie.

Considering the general classification, which takes into account all types of small RES power plants, two provinces, namely Podlaskie and Lubuskie, did not improve their position and remained in class 4, while the provinces Kujawsko-Pomorskie, Lubelskie and Podkarpackie improved their position.

Based on the data from 5 years (2016–2020), it can be predicted that in the following 5-year period from 2021 to 2025 there will be a systematic growth in the total installed electrical capacity of more than 50 kW and less than 500 kW (Figure 14).

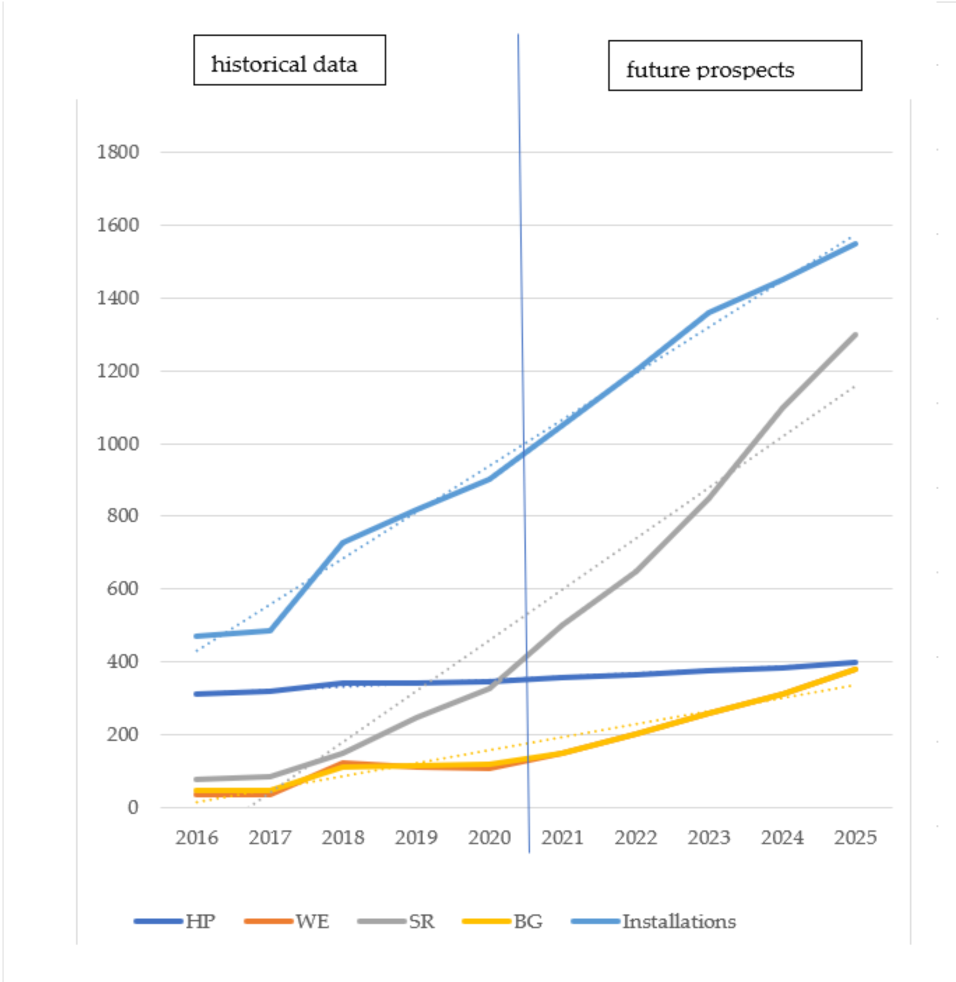

Figure 14. Current status and prospects for the growth of small RES power plants in Poland. Source: the authors.

In 2025, the number of small RES power plants could increase by nearly 70% relative to year 2020. A small increase is likely to occur in the installations using hydropower (a rise by 15% between 2020 and 2025). A surprising finding was the nearly identical development of power plants using wind power and biogas (other than agricultural biogas). In the diagram, lines illustrating the prognosis of their development overlap each other, and the number of wind-power plants was predicted to increase by approximately 233% and those using biogas by 207% between 2020 and 2025. The most spectacular increase could appear in the development of solar power plants—their number is foreseen to increase by almost 300% over these 5 years. However, it is worth noting that their dynamic increase had already taken place in the time period preceding the forecast. Biomass was not included in the prognosis due to its small contribution.

5. Discussion

The development and transformation of the energy sector in Poland is laid out in the strategic document *Energy Policy of Poland until 2040* (PEP 2040) [125] The European Union's climate and energy policy, including its long-term vision of achieving EU climate neutrality by 2050 and the regulatory mechanisms to stimulate the achievement of effects in the coming decades, has a significant influence in shaping the national energy strategy. The main objective is such a transformation of the energy sector that it will contribute to the implementation of the Energy Union and to the construction of a single EU energy market. This is planned to be achieved through the implementation of eight specific objectives. One of them is the development of RES. Another one, raised more recently, is the development of nuclear energy.

On 29 March 2022, the Council of Ministers approved the guidelines for updating the *Energy Policy of Poland until 2040* (PEP2040) by strengthening energy security and independence, which had been submitted by the Minister for Climate and Environment. The updated energy policy of Poland will now comprise the fourth pillar, energy sovereignty, in which an important role is attributed to ensuring the rapid independence of the domestic economy from fossil fuels imported from the Russian Federation. The above assumptions envisage greater technological diversification and the consistent implementation of nuclear power, as well as the improvement of energy efficiency and further diversification of supplies in addition to providing sources of energy alternative to crude oil and natural gas. The undertaken measures will aim towards the development of new, low-transmission technologies and their integration into the system. Activities reinforcing the development of electric power grids and energy storage capacity remain a priority; meanwhile, due to the current uncertainty on the natural gas market, the consumption of coal units may increase temporarily.

Ursula von der Leyen, President of the European Commission, has expressed a similar opinion on becoming independent from imports from Russia: "The European Union must gain independence from Russian gas; Moscow is no longer a credible partner". Nowadays, Europe imports 90% of its gas, and 45% of this import is from the Russian Federation. However, the European Union has a different approach to using fossil fuels. The European Commission has announced the launch of a turbo boost plan called Fit for 55, which is a package of many instruments with the aim to lower CO_2 emissions by 55% by the year 2030 [126–128]. What was a climatic necessity a year ago has now become crucial from the geopolitical standpoint. The less fossil fuels are used, the more independence the EU has from Russia.

Over the past twenty years, Poland has paid more than 900 billion Polish zloty for imported energy resources from Russia. In recent years, we have noted one of the highest increases in the import of fossil fuels among the EU-27 countries. At present, slightly less than half (46%) of our energy demand is satisfied with imported resources. In Poland, it is necessary to continue the support for photovoltaics. This is of key importance for the improved energy security of Poland. Another key target is to improve the integration of RES in the power grid. Accelerated development of heat pumps is also recommended [109].

All over the world, the development of the energy sector is strongly associated with supporting renewable energy sources (RES) [129–133]. Their biggest advantage in the struggle for an adequate condition of the global climate is that they contribute to decarbonization by emitting less carbon dioxide (CO_2) than fossil fuels when converted into energy [134,135]. Data provided by the International Renewable Energy Agency [136] as of the end of year 2021 show that the energy generation capacity from renewable sources reached 3064 GW [136]. It seems important to use local sources in the development of small renewable energy power plants [137–139].

It is therefore worth looking at the structure of electric power generation in Poland. Over recent years, it has undergone some small but noticeable changes. At the end of 2019, according to the Energy Regulatory Office (URE) in Poland [12], the installed capacity of all renewable energy sources in Poland's electric power grid was nearly 10 GW, of which small renewable energy power plants generated over 183 MW. It needs to be underlined that such installations constitute an almost negligible share, 0.37%, of all power-generating facilities (Figure 15).

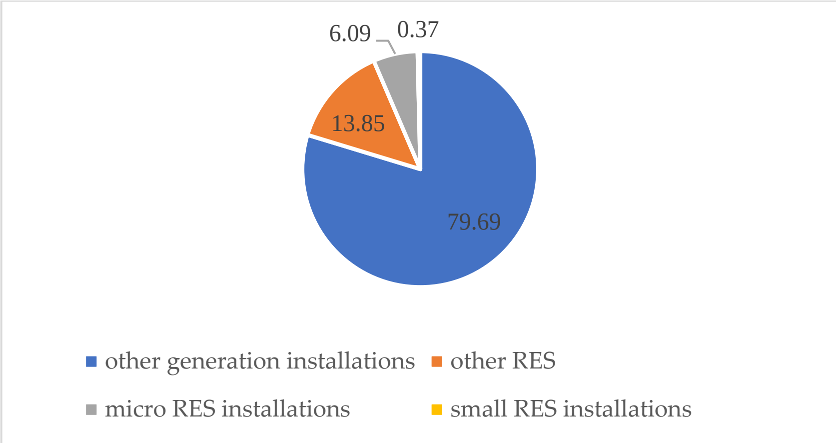

Figure 15. Structure of electric power generation (%). Source: the authors, based on [12].

The achievement of the set levels of RES in gross final energy consumption is planned primarily through the development of dispersed energy. Dispersed energy, based on installations with relatively small capacities, is the basis for the development of the local energy dimension, and gives the energy transition a participatory character. In addition to large business projects, much smaller entities (small RES) can participate in the construction of a low-carbon energy system by actively engaging in the energy transition process.

It is difficult to make adequate comparisons with other countries in Europe or in other continents because of differences in typologies regarding energy capacities [140–145]. However, attention is drawn to the fact that power plants that are classified as micro-installations, i.e., with a capacity of up to 5 kW, are particularly popular in different parts of the world. For example, studies conducted in California (the US state with the highest number of renewable energy power plants on farms) showed that the use of micro- or small power plants for commercial purposes depends on the type of production on a given farm and whether a farmer is retired or not. Other studies concerning sustainable agriculture proved that the above development depended on environmental practices, the size of a farm, the Internet connection, and the place of residence on a farm. However, the farmer's age and share in revenues were determined to have a negative effect on a decision to produce energy from renewable sources [146]. It has also been determined that electric power prices have an impact on a household's willingness to adapt to power generation, which was even suggested by some older investigations [147–150]. The idea to make a transition of the power industry to renewable and small-scale energy is gaining popularity, not only because of environmental protection issues and preservation of natural resources for future generations, but also to solve systemic problems arising from the wear-out of equipment and the lack of innovative technologies that could contribute to the modernization of the existing power capacities to increase the efficiency of the power industry [132]. An example of communities keen on tapping into renewable energy sources is found among inhabitants of Greek islands. These communities are characterized by the awareness of maritime heritage and resourcefulness. Kythnos, Ikaria, Sifnos, Tilos, Agios Efstratios, Crete and Halki are the islands that have launched the implementation of innovation projects and/or initiatives at the local level [151,152]. It is worth noting the promotion of small projects, with campaigns conducted among local residents to show the positive effects of renewable energy.

The rapid development and increase in the number of small RES power plants can be a way for Poland to become independent from imports of energy resources. Thus, the possibility of further increasing their number is now a crucial challenge. It needs to be added that following the new definition of small RES installations, there will be a large increase in their number in the subsequent report (year 2021). Nevertheless, on the basis of data from the years 2016–2022, it is possible to foresee changes in the number of RES power plants with a total installed electrical capacity of more than 50 kW and less than 500 kW.

The results of this study allow us to diagnose the current situation and predict the future development, and possibly suggest some support for particular types of installations, depending on the natural and economic characteristics of areas. The added value of this study arises from the fact that previous studies have focused on micro-installations or large power plants. Small RES installations have not been investigated thoroughly, although they can represent a very good contributor to the energy mix. This study has demonstrated that both the number of small renewable energy power plants and their capacity varies. Despite concerns, the pandemic has not significantly affected the development of RES in Poland.

Shaikh et al. stated that the pandemic has caused a crisis in the renewable energy industry by reducing the workforce and negatively impacting the economy worldwide, but the demand for the resource has increased, as many studies have proved that renewable energy is economically more attractive. "Consequently, due to the economic crisis during the pandemic, the revenues of many companies around the world have fallen. However, renewable energy firms have felt an increase in investment as the need for their product to restore economic growth in many countries is evident" [153].

However, the impact of the COVID-19 pandemic on the renewable energy sector should be mentioned, as it also suffered from the diversion of funds to healthcare, labor shortages due to lockdowns and quarantine, and shortages of critical components.

Olabi et al. found a negative impact of the COVID-19 pandemic on the renewable energy sector, especially in countries with the greatest RES potential, such as the U.S., China, India and the EU. Attention has been paid to the stimulus packages put in place by governments around the world and their sustainability to strengthen the RES sector. The launch of RES projects has stalled due to a lack of funding allocations and interruptions in the supply of equipment and components because of blocking measures [154]. Khanna [155] has described the pandemic as "a cloud with a silver lining for renewable energy". He considered the pandemic to be "an action of creative destruction" or "demand destruction" for fossil fuel industries with the significant drop in prices and employment levels, which can be seen as an opportunity to abandon dependence on fossil fuels, with a great opportunity to build back better, considering the use RES for power supply, depending on social and political responses and technological realities [154].

Although the pandemic has disrupted economic processes, its negative impact on the energy industry may bring some opportunities when appropriate mitigation strategies and policy recommendations are put in place for the post-pandemic COVID-19 period. "Economic stimulus packages announced around the world along with increased green financing may be beneficial for increasing RE growth rates" [154].

6. Conclusions

Conditions for the development of each type of RES vary across Poland. For example, the best wind conditions are in the central, most northern parts of the coastline from Koszalin to Hell; on and around Wolin Island; in the Suwałki Region; in central Wielkopolska; Mazowsze; Beskid Śląski and Beskid Żywiecki; and in the Bieszczady Mountains. Most of Poland's territory, due to the wind conditions, is unsuitable for constructing large wind farms, but relevant research suggests that there is potential for the development of small wind-power plants using local wind patterns. The best sunshine for solar power development, studies show, is in south-eastern Poland.

Despite concerns, the pandemic has not significantly affected the level of RES development. However, in 2021, this renewable energy sector started to encounter serious problems that could affect its immediate future. One of these obstacles is the inadequacy of the grid to accommodate such a large number of PV installations, as a result of which, in some places, connecting new facilities may soon become impossible.

Future detailed studies may take into account the described conditions for the development of different types of RES in individual provinces. Such studies can verify whether the actual development of small-scale RES power plants is related to environmental, social, economic or technological conditions in the areas concerned.

The findings presented in the article may have implications for predicting the impact of future pandemics and crises caused by unforeseen events. They are also the beginning of further insightful research into the factors affecting the development of RES.

Some difficulties were encountered during the research, especially related to amendments of legal definitions of the facilities investigated in Poland, and the impossibility of comparing results in subsequent years.

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Conflicts of Interest: The authors declare no conflict of interest.

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