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Development of Renewable Energy in View of Energy Security—The Study of the Photovoltaic Market in Poland

Dorota Starzyńska [1,*] and Anetta Kuna-Marszałek [2]

[1] Faculty of Management, University of Lodz, 90-237 Łódź, Poland
[2] Faculty of Economics and Sociology, University of Lodz, 90-255 Łódź, Poland; anetta.marszalek@uni.lodz.pl
* Correspondence: dorota.starzynska@uni.lodz.pl

Abstract: In recent years, the issue of energy security has been the subject of many studies, debates, and discussions. Undoubtedly, geopolitical crises in Eastern Europe and the actions of the EU as part of the continuous development of the EU's climate and energy policy have contributed to the advancement of discussions in this area. Due to the growing role and importance of energy in the economic systems of individual countries, the need to guarantee energy security is commencing to be regarded as an element of the economic security of the state and therefore, national security. The legal solutions adopted in Poland in recent years and the launch of government support programs for the development of micro-installations and prosumer energy have led to the rapid development of this sector. The aim of this article is therefore to assess the conditions of renewable energy sources development in Poland on the example of photovoltaics in the line of energy security concept. The empirical results emphasize that the development of photovoltaic is so dynamic for several reasons, primarily due to lower technological costs, stakeholder cooperation, confidence in the regulatory environment, as well as the high interest of the Polish public in this issue.

Keywords: sustainable energy transformation; energy and climate change; clean energy; renewable energy sources; PV energy; energy security

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Citation: Starzyńska, D.; Kuna-Marszałek, A. Development of Renewable Energy in View of Energy Security—The Study of the Photovoltaic Market in Poland. *Energies* **2023**, *16*, 6992. https://doi.org/10.3390/en16196992

Academic Editor: Jesús Manuel Riquelme-Santos

Received: 7 September 2023
Revised: 1 October 2023
Accepted: 6 October 2023
Published: 8 October 2023

1. Introduction

Energy is the essence of any production process and it is among the most valuable strategic resources necessary for the independent and efficient functioning of countries and societies [1,2]. Global energy consumption has increased nearly every year for more than half a century, with the exception of the early 1980s and 2009 following the financial crisis [3]. Just in recent decades, the worldwide use of energy has risen exponentially, ranging from 8532 million tons (Mtoe) in 1990 to 14,585 Mtoe in 2022 [4]. Therefore, the continuity of energy supply is undoubtedly one of the most important economic challenges today, and various government institutions, such as the World Energy Council, the Organization of Petroleum Exporting Countries, and world mega-oil organizations have conducted numerous future global energy forecasting studies [5]. According to International Energy Agency [6], global energy demand is predicted to trend towards stability until 2030, after which energy demand should grow in pace with GDP. This is essentially due to the growth of the emerging markets and developing countries, led by China, India, and other Asian regions [7–9].

It is therefore clear that modern states prioritize energy security [10]. It is a crucial global issue and a core element of both energy management and global economy environment [11], which is due to the increasing concerns over energy supply security. Recent events like the COVID-19 pandemic and the geopolitical crisis in Eastern Europe have impacted global energy markets, causing energy price shocks and disrupting energy supplies. Environmental issues like climate change can be discussed in the same context. Extreme weather events such as floods, hurricanes, droughts, and low water levels are forcing the search for new sources of energy and transformation in energy management and governance models. Not surprisingly, the aforementioned problems are becoming increasingly relevant to the contemporary energy policies in various countries, and have become major concerns for political decision-makers [12]. Policymakers need to find a new energy mix to provide stable but also publicly acceptable energy supply in the future [13].

Measures to improve energy security include an increased use of renewable energy sources (RESs), which would allow for at least partial independence from external supplies of resources. With the support of effective policy and innovative business models, the use renewable energy can experience a considerable growth and shape energy security in many countries in the near future [14,15]. According to IEA [6], by 2030 we will notice a stronger push for renewables, faster electrification of industrial processes, vehicles, and heating. Thus, the current global energy crisis may prove to be a historic turning point towards a cleaner future, which would accelerate the transition to a more sustainable and secure energy system. It would also have some economic benefits. According to IRENA [16], by 2025, energy transformation would boost GDP by 2.5% and total employment by 0.2% globally. Every dollar spent in transforming the global energy system provides a payoff ranging from USD 3 to more than USD 7, depending on the study [16].

The IEA predicts the world is set to add as much renewable power in the next 5 years as it has in the past 20 [17]. This is in line with commitments made by most countries aimed at achieving a net zero carbon footprint in the coming years. It is also anticipated that total worldwide growth of renewable power capacity is set to almost double, overtaking coal as the largest source of electricity by early 2025 globally [17]. Low-carbon sources are expected to cover nearly 90% of the total projected boost in the global electricity demand between 2023 and 2025, whereas China is forecast to be responsible for more than 45% of the growth in renewable energy production. The European Union, on the other hand, is expected to account for 15% of the increase in total production [18]. It would be a big challenge for the EU Member States which have also adopted ambitious targets for the deployment of renewable energy systems. They have chosen to rely on wind and photovoltaics. However, in the past 10 years, the majority of Member States have deployed renewable energy technology sporadically rather than continuously, which has caused several markets to perform below their potential [19].

In 2020, the EU was a net importer of energy with a level of energy dependence reaching almost 55.5% in 2021 [20]. This explains the European Commission's growing concern to increase the energy security of the EU. Many studies show that this security varies throughout the EU [21,22]. For example, countries in the western European region (e.g., Germany and France) have higher energy security than southern Europe (e.g., Italy and Spain), primarily due to the more developed infrastructure and a richer energy mix.

To compensate for these disparities, a number of plans and institutional solutions have emerged (i.e., Renewable Energy Directive, Clean energy for all Europeans package). In reaction to the difficulties and disruptions in the global energy market that occurred in 2022, another plan was adopted, namely, REPowerEU [23]. It is aimed at accelerating the transition to clean energy and gradually reducing EU countries' dependence on Russian fossil fuels. The European Commission has proposed installing heat pumps, increasing the capacity of photovoltaic systems, phasing in the mandatory installation of solar panels on new buildings, and importing renewable hydrogen and biomethane to raise the 2030 renewable energy target to 45%.

The above-mentioned regulations apply to all Member States, including Poland which has high potential in the use of RES, although the share of coal in gross electricity production is high. In 2022, it amounted to 70.7%, which was 1.7 p.p. less than in 2021. However, it is worth noting that in 2022, for the first time, the production from RES in Poland exceeded 20% of the mix. It amounted to 20.6%, thanks to the record production of 36.8 TWh and a 1.9% reduction in electricity demand. Photovoltaics is the largest contributor to the energy transition, as up to 53.4% of the renewable electricity generated in Poland comes from solar power. Next in line is wind energy (36.4%). In contrast, water (4.8%) and biomass and biogas (5.4%) are smaller contributors to green energy in Poland [24]. The potential for electricity production from photovoltaic panels in Poland is not significantly different from that of the neighboring countries situated at a similar latitude and is about 1000–1100 kWh/kWp3. However, it is significantly lower than the production achieved by South European countries. Recent years have shown a clear increase in the production of energy from photovoltaic panels in Poland, which is mainly due to the popularization of photovoltaic panels installed by prosumers.

The purpose of the article is to diagnose the photovoltaic market (as a sub-market of renewable energy sources) in Poland and to show the potential and prospects for its development. We posed the following research questions: What is the current status of the photovoltaics sector in Poland and in the EU in comparison with other renewable energy sectors? What are the determinants and opportunities for its growth? What challenges does the photovoltaics sector face in the coming years?

The article begins with the introductory section and the literature review that reveals the complexity of the concept of energy security, and addresses the possibility of ensuring it through the use of renewable energy sources. Then we assess energy efficiency in Poland in 2011–2021, analyze macroeconomic indicators of energy intensity, and show the potential of development of RES in particular photovoltaics. We also refer to new trends and phenomena serving the prosumer market, whose development in Poland is very dynamic. The article ends with conclusions, and an indication of further possible research directions.

The research is based on the analysis of industry reports on the energy market in the EU countries, as well as statistical studies on the photovoltaic market in Poland. There is a limited number of domestic studies dedicated to assessing the prospects of the photovoltaic industry in the context of energy security. In the analysis, we mainly used foreign scientific articles, international reports, forecasts, and statistical data, such as Polish Central Statistical Office data on energy efficiency, energy consumption and the use of renewable energy sources in final energy and electricity consumption. The analyzed market was divided into three segments: micro-installations with a capacity not exceeding 50 kW, small photovoltaic installations with a capacity in the range of 50–1000 kW and large photovoltaic farms with a capacity above 1 MW.

The issues discussed are significant for a number of reasons. First of all, renewable energy is gaining importance in the energy mix, and its rapid growth is catalyzed by the concepts of energy security, energy transformation, or climate policy. Therefore, it seems undisputable that RES should be the basis for the development of the energy market in numerous countries. Photovoltaics can contribute to a breakthrough that would accelerate Poland's energy transition. It is a major area of investment in renewable energy and the entire Polish electric power industry. It is also worth noting that it is the only RES sector that has been able to mobilize more investment capital in recent years than the entire conventional power industry. In our article, we also reflected on new trends and phenomena in the prosumer market whose development in Poland is very dynamic. Awareness of the ongoing changes and the prospects for development are particularly relevant to the contemporary energy policies, and these issues should become major concerns for political decision-makers worldwide, especially since the development of prosumer energy is associated with many socioeconomic benefits. Such knowledge would lead to the formulation of new goals for ensuring energy security and pushing the energy market toward green growth.

2. Literature Review

2.1. Energy Security

Energy security is an issue historically associated with the depletion of fossil fuels, in the result of which the security of supply has become a particularly important concern [25]. It is defined in a variety of ways in the research literature with no clear consensus. Those definitions do, however, contain certain dominant aspects [26–30]. They include: energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency [29]. In general, energy security is connected to risk management and energy management [11]. In the short term, this relates to the ability of the energy system to quickly respond to sudden changes in the supply–demand balance. However, in the long term, energy security concerns are associated with timely investment in energy supply in line with economic development and ecological issues. In the context of state, energy security is one of the key elements of economic security [31–34], where an important aspect is energy price [35]. Contemporary definitions of energy security exceed the aspect of protecting the supply of main energy sources to include environmental, social, and economic concerns, as well as the operational reliability of energy systems [36].

The IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price" [37]. The EU also emphasizes the critical importance of 'a stable and abundant supply of energy' for European prosperity and security. This approach is supported by a number of studies which find that energy security plays a significant role in both national economic growth [38–41] and human life [42,43].

The concept of energy security is important primarily for the energy consumer who should be guaranteed energy in the form and quantity needed, at the required time and at an available price. The state's task with regard to the energy sector should be to ensure a high level of energy security, understood as a supply, economic (certainty that energy prices will not create a barrier to economic development and will not lead to energy poverty), or environmental security (energy production will not cause excessive environmental pollution).

The European Union has established energy security as one of the cornerstones of its energy policy [44]. Throughout the years, it has taken a number of measures to ensure energy security, such as the creation of the Energy Union in 2015 to ensure free flow of energy between EU countries and reduce dependence on imports. It has, nevertheless, failed to make the economies of its Member States immune to disruptions, such as the COVID-19 pandemic or the 2022 cut-off of gas supplies from Russia. Therefore, it would be more reasonable to place more emphasis on diversification of energy sources and, as raised with increased intensity in public discourse, greater use of alternative energy sources. In the document of 18 May 2022, the European Commission also emphasizes that internal energy security requires "diversifying the EU energy supply, increasing energy savings and efficiency and accelerating the green energy transition" [45].

2.2. The Role of Renewable Energy Sources

In consequence, fast development of renewable energy sources seems to be a matter of time, especially as many studies point to their contribution to economic growth, the promotion of local socio-economic development, better environmental protection and, above all, worldwide cooperation to reduce global warming [15,46–49]. Setting ambitious goals such as, among others, cutting greenhouse gas emissions by at least 55% (compared with 1990) by 2030, and becoming a climate-neutral continent by 2050 would speed up the transition to sustainable energy. These initiatives have begun to bear fruit, with an increasing proportion of Europe's energy needs being met through renewable energy sources. In 2021, more than 22% of gross final energy consumed in the EU came from renewable sources [50]. However, their share in the energy mix varies considerably from one EU country to another: in Sweden, it is around 60%, in Denmark, Estonia, Finland, and Latvia, it is over 40%, and in Belgium, Hungary, Ireland, Luxembourg, Malta, and the Netherlands, it is between 10% and 15% [50]. Between 2005 and 2021 the renewable energy share in the EU grew by an average 0.8% per year.

There are also significant differences in the speed and motivation with which Member States are pursuing the transition towards clean energy. Some EU countries are strongly promoting renewables (e.g., Germany, Denmark), while others are actively resisting it (i.e., Poland) [51]. Observations in recent years have shown that in Western European countries, renewable energy is regarded as a means to bring these countries closer to energy independence and security, providing opportunities for further industrial development. In

Eastern European countries, on the other hand, there is a concern about fossil fuel industry workforce and electricity prices. It appears that renewable energy is perceived as a win-win in the West and a win-lose in the East [51].

The transition to renewable energy sources is a major challenge. In order to promote their use, ensure uninterrupted energy supply and lower transmission costs, Europeans are being encouraged to become prosumers who generate electricity with, e.g., solar panels, consume it and feed it into the transmission grid. The benefits of doing so are numerous: from savings thanks to lower energy costs, to accelerating Europe's energy transition and reducing greenhouse gas emissions [52–55]. Other benefits worth noting are the creation of local jobs, circumventing land use, escaping transmission costs and increasing grid flexibility [56]. According to data provided by the International Renewable Energy Agency (IRENA), the RES industry already employed more than 7.3 million people worldwide at the end of 2012, but in 2021 this number grew to about 12.7 million (of which the largest group of people, 4.29 million, were associated with the solar photovoltaic industry, while the smallest one, 0.77 million, were related to solar heating/cooling) [57]. Close to two-thirds of all jobs were in Asia (China alone accounts for 42% of the global total), followed by the European Union and Brazil with 10% each, and the United States and India with 7% each [57].

Individual EU countries use a variety of financial incentives to develop the prosumer market, such as low-interest and long-term loans, environmental tax exemptions, feed-in tariffs, or premiums with specific measures tailored to prosumers. Incentives should also aim to encourage the development and implementation of new technologies designed to protect the environment [58].

2.3. Renewable Energy in Poland

The dynamic development of renewable energy in Poland began after it joined the EU. Poland's installed capacity of renewable energy sources increased from 11.6 GW in 2005 to 23.4 MW in April 2023. According to the Ministry of Climate and Environment's statement, this growth is expected to be exponential in the coming years. According to the assumptions of the update to Poland's Energy Policy until 2040, by the end of the decade, the installed capacity of RES will reach 50, and 88 GW by 2040 [59].

In recent years, there has been a significant increase in the total domestic consumption of renewable energy, i.e., between 2017 and 2021, the increase was 44.38% [60]. Renewable energy generated in Poland includes energy from solar radiation, water, wind, geothermal resources, energy generated from solid biofuels, biogas and liquid biofuels, as well as ambient energy from heat pumps. As far as domestic acquisition (and use) of energy from renewable sources, solid biofuels occupied a dominant position. Compared with 2017, their share in obtaining energy from renewable sources in 2021 amounted to 69.35% and increased by 2.59 percentage points. Between 2017 and 2021, the share of wind energy decreased from 13.89% to 10.90%, biogas: from 3.04% to 2.49% and water energy: from 2.38% to 1.57%. At the same time, the share of solar energy increased from 0.74% to 3.31%. In 2021, solar energy (516%) achieved a relatively high position in obtaining energy from renewable sources by carrier, followed by heat pumps (102%), and then biogas, water energy, municipal waste energy, and geothermal energy, respectively [60].

A similar trend can be observed worldwide. Among renewable technologies, solar photovoltaic installations grew the fastest, with a twenty-six-fold increase in the 13-year period from 2010 to 2022. This was due to significant cost savings generated by technological advancements, high learning rates, policy support and innovative financing models [61]. In the EU, the REPowerEU plan introduced a strategy to double solar photovoltaic capacity to 320 GW by 2025 and install 600 GW by 2030. The plan also included a phased-in legal obligation to install solar panels on new public, commercial, and residential buildings [62]. This will certainly be reflected in employment in the sector as well. IRENA's estimates for upcoming years make Poland home to the largest solar PV workforce on the continent [61]. Among top ten countries where solar PV employment will grow, Poland ranks 6th (behind

China, United States, India, Japan, Bangladesh, Brazil), ahead of Germany (8th), Vietnam (9th), and Australia (10th) [61]. Therefore, it seems that the popularity of solar photovoltaic energy resources will grow in the near future, especially since technologies are developing rapidly, including the market for so-called organic photovoltaic cells [63], the total cost of installing photovoltaic projects is projected to continue to decline over the next three decades [16], existing integration strategies and those under development will allow large penetration of solar PV not only in the power grid but in the entire energy system [64].

The complementarity of solar PV with, for example, wind energy is already being noted [16,65]. Although wind power will probably remain one of the major electricity generation sources, supplying more than one third of total electricity demand, solar PV power should follow, supplying 25% of total electricity demand. According to IRENA [16], it would represent over a tenfold rise in the solar PV share of the generation mix by 2050, in comparison with 2016 levels.

The role of photovoltaics in the energy transition is gaining recognition in Poland [66–69]. There are a number of factors contributing to the expansion of the photovoltaic user pool: ease of installation, simplicity of construction, relatively low costs, low labor intensity, no need to purchase fuel, and the ability to scale the installation depending on the capital [68]. Traditional centralized power systems, dominated by large conventional units controlled by few players, are being replaced by systems based on distributed generation capacity. Thus, a large part of energy can be generated by a group of producers including households and companies for which power generation is not the main business. The most important goals that can be achieved through such activities include [70]:

- Increased competition in the energy market which will consequently lead to a decrease in prices;
- The possibility of implementing a number of small investments, characterized by a relatively large total installed capacity;
- Stimulation of the development of innovative technological solutions, especially smart grids;
- The involvement of private capital in the development of a low-carbon economy;
- Technological diversification in the electricity system;
- A broadly understood improvement in the environment, both locally (improving air quality) and globally (combating climate change);
- Increased public awareness of energy transition and security.

3. Methodology and Results

3.1. Energy Efficiency and Energy Consumption

The first stage of the analysis is the assessment of energy efficiency in Poland in the years 2011–2021. Increasing the energy efficiency of power generation, transmission and use is a pillar of sustainable energy policy. This is reflected in legislation and actions taken by national and EU institutions. The priority of increasing energy efficiency is expressed in Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency (revised EED Directive), which entered into force on 24 December 2018 [71]. The revised EED Directive sets as a target an increase in energy efficiency of at least 32.5% in 2030, while assuming that in 2030, primary energy consumption in EU countries will not exceed 1273 Mtoe, which is about 53.3 million TJ. For Poland, the national energy efficiency target for 2030 has been set at 23% for primary energy consumption according to the PRIMES 2007 projection, which corresponds to a primary energy consumption of 91.3 Mtoe in 2030 [72].

Figure 1 presents data on total primary energy consumption in Poland in 2011–2021. Between 2011 and 2014, overall primary energy consumption followed a decreasing trend, reaching a low of 89.5 Mtoe in 2014. Since 2015, this variable has been steadily increasing, reaching its highest level in 2018, when primary energy consumption amounted to 104.1 Mtoe. In the years 2019–2021, another decline was observed, which was the result of the COVID-19 pandemic. In 2021, compared with the baseline year, the total energy consumption increased by 7.7% and on average, rose by 0.75% year by year.

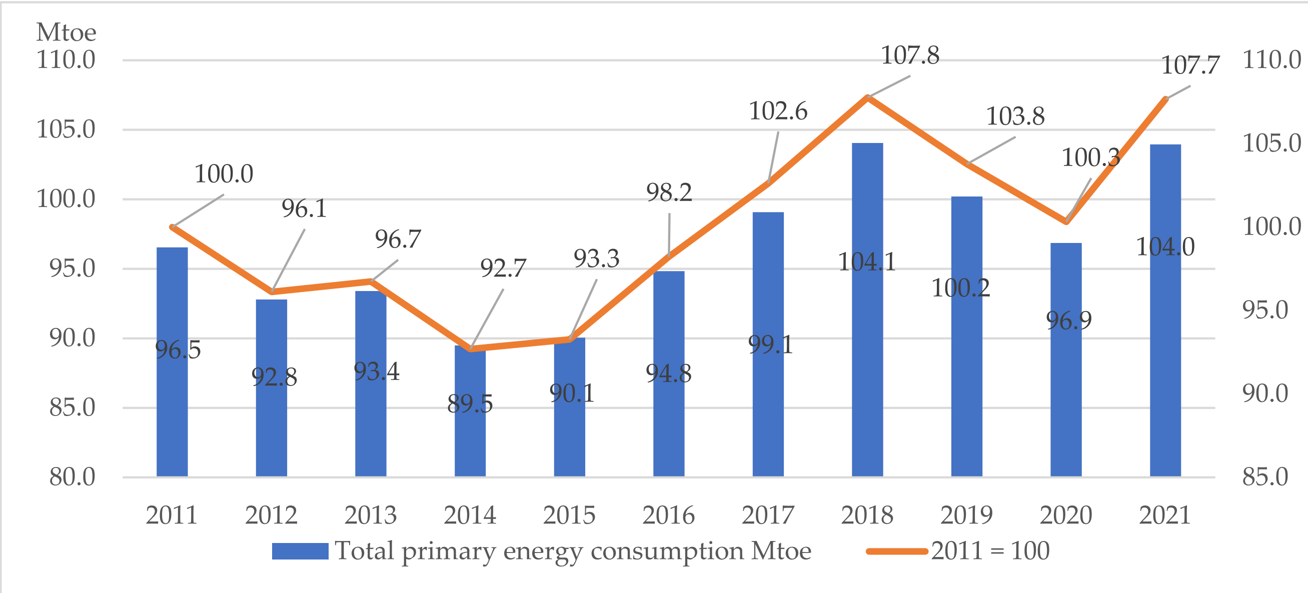

Figure 1. Total primary energy consumption in Poland in the years 2011–2021 [Mtoe]. Source: own calculation based on [72].

Another variable analyzed is the final energy consumption, which in the studied period increased from 64.7 Mtoe to 75.2 Mtoe. In the years 2011–2021, final energy consumption on average increased by 1.5% per year (Figure 2).

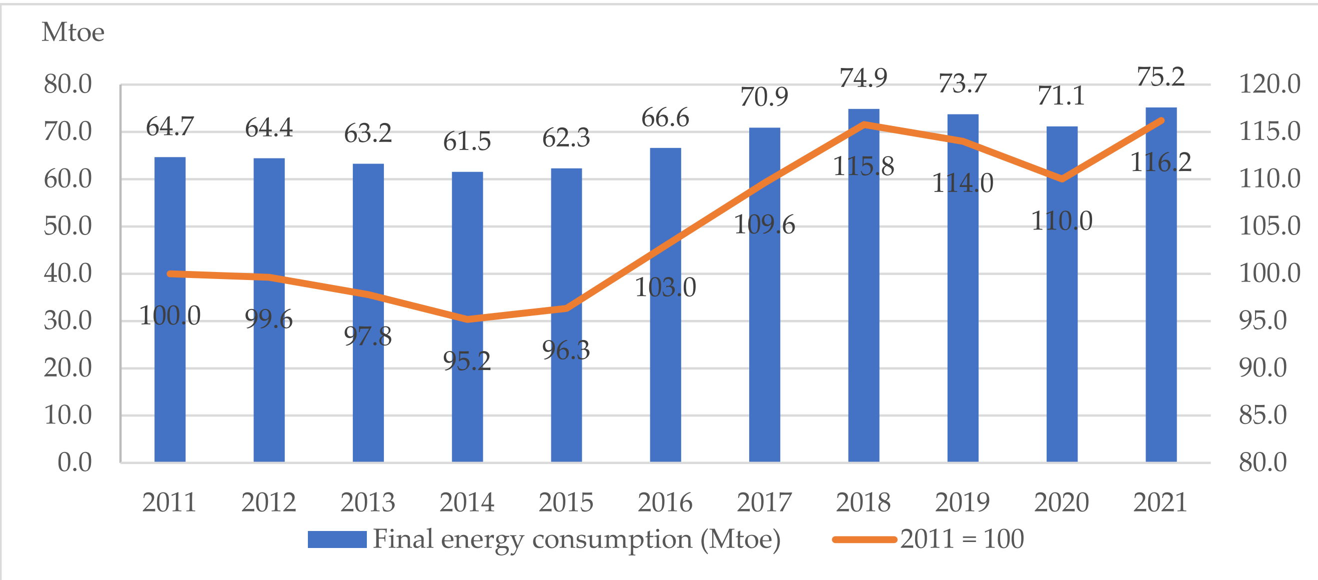

Figure 2. Final energy consumption in Poland in the years 2011–2021 [Mtoe]. Source: own calculation based on [72].

The structure of final energy consumption in Poland according to the energy sources used is largely determined by the available natural resources. In both 2011 and 2021, fossil fuels remained the main source of primary energy. In the case of solid fossil fuels (mainly hard coal and lignite), a decrease in their share in the final consumption was observed from 20.3% in 2011 to 13.0% in 2021.

The most important energy source in 2021 was liquid fuels, i.e., crude oil and petroleum products (excluding biofuels), whose share amounted to 34.8% and, in comparison with 2011, increased by 3.6 p.p. (Figure 3). An increase in the share was also recorded for natural gas: from 13.2% in 2011 to 14.3% in 2021, and other energy sources (mainly RES): from 10.1% to 13.6%. A slight rise in the share was recorded for electricity: from 16.2% in 2011 to 16.4% in 2021. On the other hand, for heat, a decrease in consumption was observed: from 9.0% in 2011 to 7.9% in 2021.

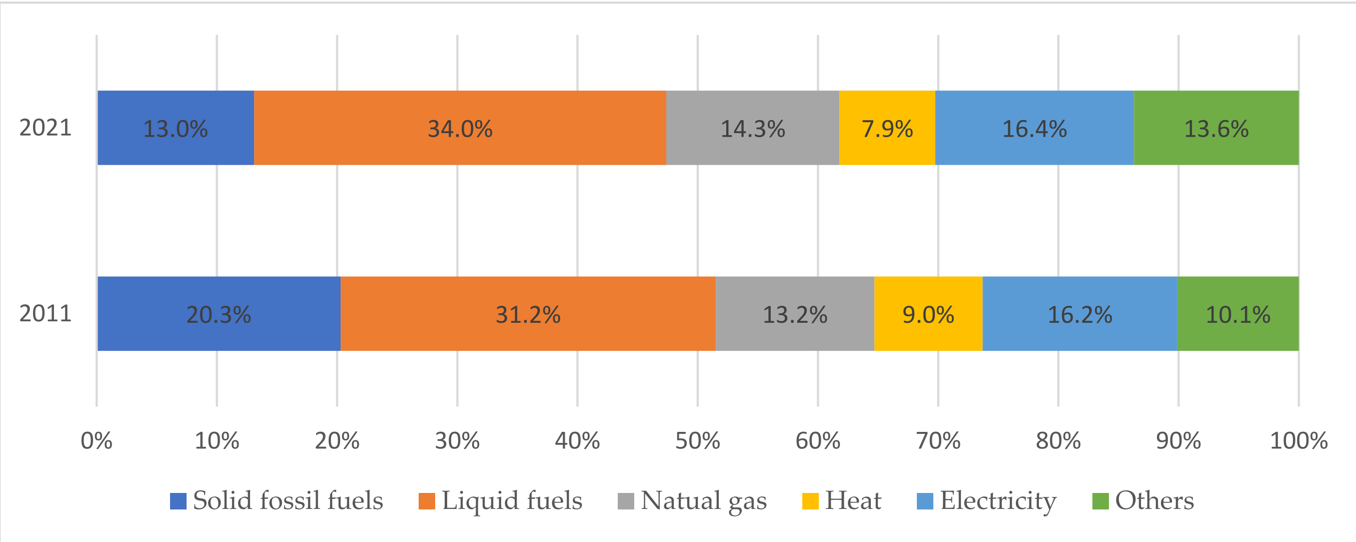

Figure 3. Structure of final energy consumption in Poland in 2011 and 2021 by source [%]. Source: own calculation based on [72].

3.2. Energy Intensity

The next stage is the analysis of macroeconomic indicators of primary and final energy intensity of GDP. In the years 2011–2021, the indicators of primary and final energy intensity of GDP steadily decreased. Compared with 2011, in 2021, primary and final energy intensity of GDP dropped by 20.3% and 13.8%, respectively (Figure 4). The exception was 2021, in which, in comparison with 2020, an increase in these indicators was recorded. Despite this increase, the primary energy intensity of GDP in the years 2011–2021 fell by 2.3% on average from year to year, and the final energy intensity of GDP decreased by 1.5% on average per year. The reduction in energy intensity means that less energy is needed to produce the same amount of GDP, which is associated with an increase in energy efficiency in Poland. The ratio of final energy intensity to primary energy intensity showed an upward trend in the period 2011–2021, reaching the highest value in 2020 (68.3%). Its level is influenced by such factors as: efficient and effective energy transformation (the greater the efficiency, the higher the value of the indicator) and the rate of increase in electricity consumption (the higher the consumption, the lower the value of the indicator and vice versa).

In Poland, in the years 2011–2021, energy efficiency improved. Primary energy intensity of GDP decreased during this period by 2.6% per year, while final energy intensity of GDP, by 1.5% per year. The fastest rate of energy efficiency improvement between 2011 and 2021 was recorded in industry, where energy efficiency index dropped by 1.3%/year; in case of households the improvement amounted to 1.1%/year while in transport, to 0.9%/year.

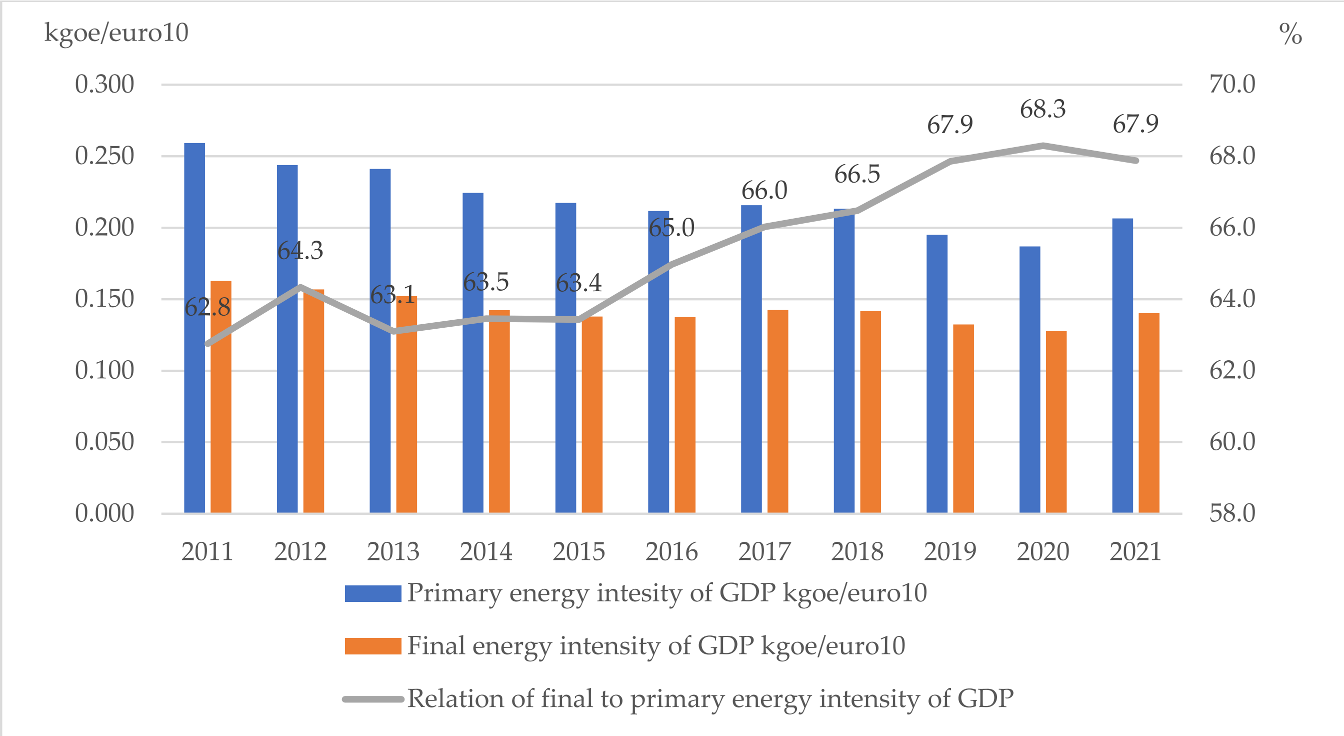

Figure 4. Energy intensity of GDP (kgoe/euro10) and relation of final to primary energy intensity of GDP [%]. Source: own calculation based on [72].

3.3. Energy from Renewable Sources

The geopolitical crisis in Eastern Europe and the related energy crisis have resulted in a revision of the energy transformation plans adopted in 2014–2020. The EU's climate goals based on the rapid development of RES (the so-called Fit for 55 package) have been correlated with the objectives related to energy security (the so-called REPowerEU package), which in Europe are implemented primarily through the use of its own renewable energy resources, including in particular solar energy. Various EU policy initiatives from 2022 to 2023, such as: EU Solar Energy Strategy, European Solar Rooftops Initiative, and European Solar Industry Alliance have given importance to photovoltaics across Europe, raising it to the level of a technology of special importance.

The RES target for Poland for 2020 has been set at 15%. Poland has met its binding target and achieved a 16.13% share of energy from RES in gross final energy consumption, although in 2021 the share of RES fell to 15.62%, raising concerns about the further pace of development of renewable energy sources (Figure 5). Official data from 2022 are not yet known, but it can be assumed that the share of RES in electricity consumption should grow. In particular, this growth is due to the spectacular development of photovoltaics that has been going on for several years and there are real prospects for maintaining this trend in the coming years. In the current decade, the EU is moving away from binding targets for RES. However, new strategic and comprehensive framework for energy and climate policy may significantly accelerate the further development of RES, in particular investments in photovoltaic power.

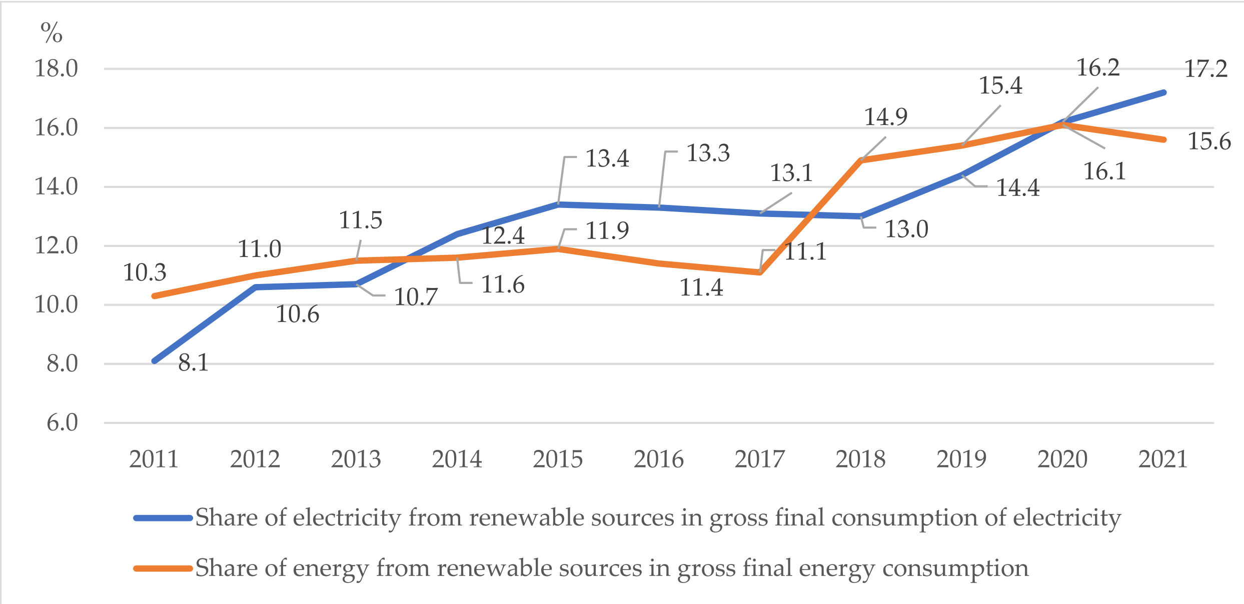

Figure 5. Share of electricity from renewable sources and share of energy from renewable sources in gross final energy consumption [%]. Source: own calculation based on [73].

In the period under review, a clear increase in the production of electricity from renewable sources can be perceived. Since 2015, energy production from RES in Poland has risen by 34.3%. In the case of biomass and gas, in 2017, there was a decrease of 35.5%, compared with the baseline year. Over the years 2015–2021, the importance of water in energy production has increased by 27.7%. Compared with 2015, the production of energy from wind rose by nearly 50%. Recent years might be perceived as the boom of electricity from photovoltaic panels. The photovoltaic market has developed in Poland very rapidly. This is also confirmed by data collected by the Central Statistical Office. Between 2015 and 2021, an increase of as much as 6800% was recorded (Table 1).

Table 1. Production of electricity by sources in Poland, RES (GWh).

Specification	2015	2016	2017	2018	2019	2020	2021
Biomass and biogas	9932	7957	6416	6511	7602	8371	7954
Water	1832	2139	2560	1970	1958	2118	2339
Wind	10,858	12,588	14,909	12,799	15,107	15,800	16,234
Photovoltaic cells	57	124	165	300	711	1958	3934
Total RES	22,679	22,808	24,050	21,580	25,378	28,247	30,461

Source: own calculation based on [74].

The most important fuel used to generate electricity in 2021 was hard coal, with a share of 45.7%, and lignite, with 25.5%. The share of these fuels in production has dropped by 7.9 percentage points since 2015. Production from renewable energy sources accounted for 17.0% and increased by 3.2 percentage points, compared with 2015. The most important sources in this group were wind energy, biomass, and biogas. Solar energy, thanks to significant growth dynamics, exceeded water energy in the analyzed period (Figure 6).

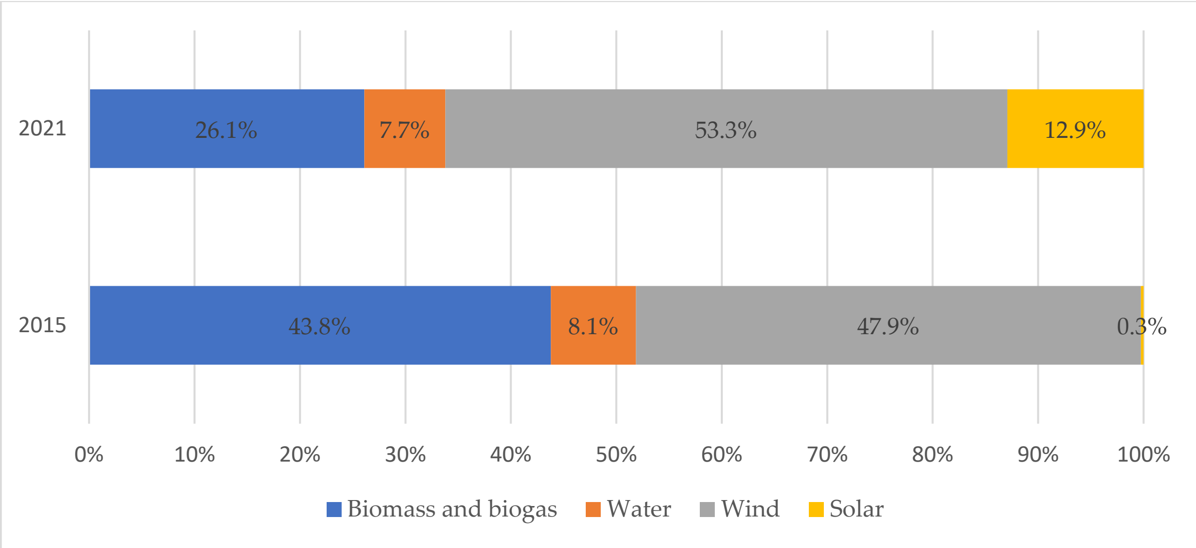

Figure 6. Share of electricity production from renewable sources [%]. Source: own calculation based on [68].

Generating energy from renewable sources has many advantages. These include the acquisition of free renewable and ecological energy, as well as independence from the supply of energy from the grid [75]. Recently, the use of renewable sources to produce electricity is gaining more and more recognition worldwide [76]. This is related to several factors, of which the key factors are economic, closely related to the increasing reduction in costs of photovoltaic installations, the support (prosumer) system, as well as the possibility of receiving subsidies and preferential loans for this type of systems.

The main problem and uncertainty accompanying the production of energy from solar radiation is the large fluctuation in the size of its production, because it mainly depends on atmospheric conditions. When planning the construction of a photovoltaic system, we are not able to accurately estimate all factors. The emergence of prosumer institutions and mechanisms allowing for net balancing of energy consumed and produced by micro-installations significantly reduces the inconvenience for the prosumer (net metering and net billing).

Photovoltaics in Poland was the leader and the main driver of the RES market growth for another year in a row. According to data from the Energy Regulatory Office, the installed capacity in PV at the end of 2022 amounted to over 12.4 GW, which, compared with 2021 (7.7 GW), meant a record increase of over 4.75 GW of new capacity (market growth rate: 61%). Extremely fast gains in PV capacity have been observed in Poland since 2019. The main reason for this success was the mass construction of micro-installations (i.e., installations with a capacity of up to 50 kW), initially almost exclusively in the household sector (Figure 7).

In 2022, almost 75% of all PV capacities were installed in prosumer micro-installations, but this time they were not only household systems, but also systems belonging to companies, installed on various types of service, commercial or sacred buildings used by the so-called self-producers. In 2022, the number of small installations (as defined by the RES Act) with capacities up to 1 MW also increased, as they do not require a license for electricity generation. These installations were almost 2.5 GW (1.5 GW in the year before), which accounted for 20% of total PV capacity. At the end of 2022, the share of large PV farms above 1 MW in PV capacity exceeded 5% [77].

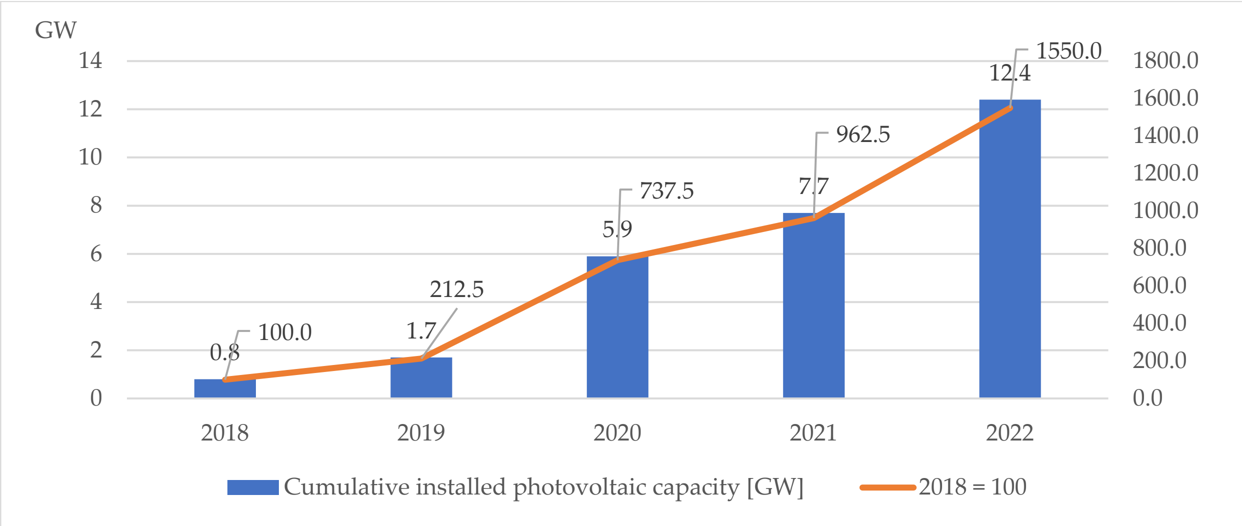

Figure 7. Cumulative installed photovoltaic capacity [GW]. Source: own calculation based on [77].

The total installed capacity in PV sources by segment at the end of 2022 consisted of:

- Micro-installations: installations with a total installed capacity not exceeding 50 kW, i.e., prosumer installations; their total capacity amounted to over 9.3 GW;
- Small installations with capacities in the range of 50–1000 kW; their installed capacity in Poland reached 2.5 GW;
- PV farms above 1 MW: total installed capacity of 645 MW.

Research conducted by Sobczyk [78] has shown that prosumption is experiencing an upward trend in Poland. The development of power industry is related to possible shortages or deficiencies of electricity in the future, predictions regarding the increase in energy prices, the need to protect the environment and issues with access to electricity in inaccessible areas.

Photovoltaic prosumerism is a Polish phenomenon of recent years, comparable only to earlier, historical "booms" in Germany, Australia, or California. However, in no country in the world do micro-installations have such a large share in the RES market and in the energy market as in Poland. The number of prosumer photovoltaic installations, according to Energy Regulatory Office data [79], at the end of 2022 was 1,212,963 units, which means an increase of over 41% y/y (at the end of 2021, it was 845,259 units). Their estimated total installed capacity reached over 9.3 GW (9307.179 MW). Prosumers in Poland have the largest share in the photovoltaic market. In 2022, they accounted for 68% of the annual increase in installed photovoltaic capacity. This is the result of growing environmental awareness and the currently uncertain market, energy, and geopolitical situation.

The key factors that contributed to such a dynamic development of photovoltaics among households and enterprises were: the energy settlement system and the subsidy system, among others, the "My Electricity" program. The category of PV micro-installations, apart from home producer installations with a maximum power of 10 kW, also includes installations built for the needs of micro and small enterprises or individual farms, and their maximum power is 50 kW. Prosumers in Poland were most eager to install photovoltaic panels until 1 April 2022, when they could use the same settlement system, the so-called net-metering. Net metering is a principle under which a person, who is both a producer and consumer of electricity, generates energy in their own micro-installation and supplies it to the distribution grid. The energy is then accounted for in kWh of energy produced per kWh of energy consumed. Individual installations are settled in the relation of the balance of energy produced and settled in the proportion of 1:0.8 in the case of natural persons and 1:0.7 for enterprises. Net-metering in Poland is settled on a semi-annual basis, which, with the right selection of settlement periods, may allow to produce in the summer the amount of energy that will meet the needs of the prosumer in winter without the need for additional energy consumption and possible costs. PV installations connected to the grid after 1 April 2022 are already settled in the new net-billing system, cash settlement system. The operation of the new system is as follows: the deposit, which replaces the virtual energy storage, contains the amount resulting from the settlement of the energy returned to the grid and the energy received from the grid. This amount is charged at appropriate rates:

- The price of sale of electricity from photovoltaics by the prosumer to the grid is the monthly rate of the Market Energy Price;
- The price of purchase of electricity from the grid is the energy tariff applicable in a given year, which depends on the area in which the prosumer operator has the photovoltaic system installed.

In the net-billing system, the settlement of photovoltaics will take place on the basis of the sale of energy to the grid, which can later be purchased, and the settlement period is 12 months counted from the date of energy introduction (this date is the last day of the month in which the energy was introduced into the grid).

The net-billing system has slightly slowed down the development of prosumer installations, mainly due to the need for installers, prosumers, banks, and financing institutions to learn new rules. However, it also provided incentives for better selection of installations and investment in additional devices that will be able to use surplus energy and increase self-consumption.

The key aspect motivating Polish households to purchase and install PV installations is the system of subsidies and discounts. In 2019, the National Fund for Environmental Protection and Water Management announced the first edition of the "My Electricity" program. The "My Electricity" program supports the development of prosumer energy. It concerns people who generate energy for their own needs and transfer its surplus to the power grid. The amount of co-financing for a single photovoltaic installation was PLN 5000 in the form of a subsidy. From the beginning of the first call in 2019 to 17 March 2023, thanks to the mentioned program, individual prosumers received support in the amount of PLN 1.85 billion [77].

Thermo-modernization relief is one of the currently used instruments for financing and supporting investments in renewable energy sources, including PV installations in Poland. It is intended for households that have invested funds in PV micro-installations with a capacity of up to 10 kW. The relief is granted to natural persons settling income taxes on general terms (income tax rates 12%, 32%), on the basis of flat tax (19%) and on a lump sum. The amount of investment in a PV micro-installation may be deducted from the personal income tax base and its maximum amount may not exceed PLN 53,000 [80]. Thermo-modernization relief is available only to owners and co-owners of a single-family house [81].

In the coming years, the photovoltaic market will continue to grow. The segment of PV micro-installations up to 50 kW is expected to remain crucial. Households, i.e., owners of single-family houses, will continue to play a particular role in this segment. For this group of entities, support in the form of a subsidy in the amount of PLN 6000 for the purchase and installation of photovoltaic panels with a capacity of up to 10 kW and thermo-modernization relief was maintained. Households of farmers are increasingly willing to invest in PV micro-installations, which is why in 2023 a new government program, "Energy for Villages", was launched. Rural areas occupy over 93% of all Polish lands inhabited by nearly 40% of the population. The rise in energy demand in these areas, combined with its increased use in agriculture, causes rural residents to make better use of energy, whereas politicians are forced to develop rural energy security strategies [82]. The Ministry of Agriculture and Rural Development has developed the "Energy for Villages" program in order to support Polish agriculture and farmers. Under the program, one can apply for co-financing for RES installations in the form of a subsidy or loan. Entities that can apply for support are farmers and energy cooperatives. The "Energy for Villages" program is an opportunity for energy transformation in rural areas. RES investments in rural areas are to be local, use locally available resources and meet local needs. Investment in RES means additional income for the countryside inhabitants, as well as lower costs of obtaining energy [83]. In addition, this group of entities is increasingly investing in small installations with a capacity above 50 kW. In the micro-installations segment, in 2023 there will be a group of potential recipients, the so-called tenant prosumers [84]. These are cooperatives, housing communities, as well as local governments with multi-family buildings in their resources. They can count on co-financing for the purchase of PV installations in the amount of up to 50% of eligible costs. Applications for co-financing can be submitted from 1 February 2023, to Bank Gospodarstwa Krajowego.

In the segment of small photovoltaic installations with a capacity of 50–1000 kW, there is also a great interest among investors. These are more and more frequently farmers who have a large acreage of agricultural properties on which photovoltaic farms or agrophotovoltaic systems can be installed. In this segment, companies and individual investors are also very active.

The last segment of the photovoltaic market in Poland are large farms with a capacity of 1 MW. Until the end of 2022, this segment grew the slowest, with a market share of just over 5%. The PV farm market is dominated mainly by private companies, energy corporations and state-owned companies. The market leader is Respect Energy (32%) with an installation capacity of over 204 MW at the end of March 2023 and plans to quickly double it.

In recent years, the costs of electricity production have been steadily increasing, which has had an impact on the sale price of electricity in Poland. In the years 2015–2017, the average annual sale price of electricity on a competitive market remained at a similar level. In the following years, a gigantic soar in the analyzed variable was recorded. In 2022, the average annual electricity sales price reached PLN 523.7/MWh which was 208.2% higher compared with the base period, i.e., 2015 (Figure 8). Rising electricity sales prices in a competitive market had a direct impact on the price of electricity purchased by households.

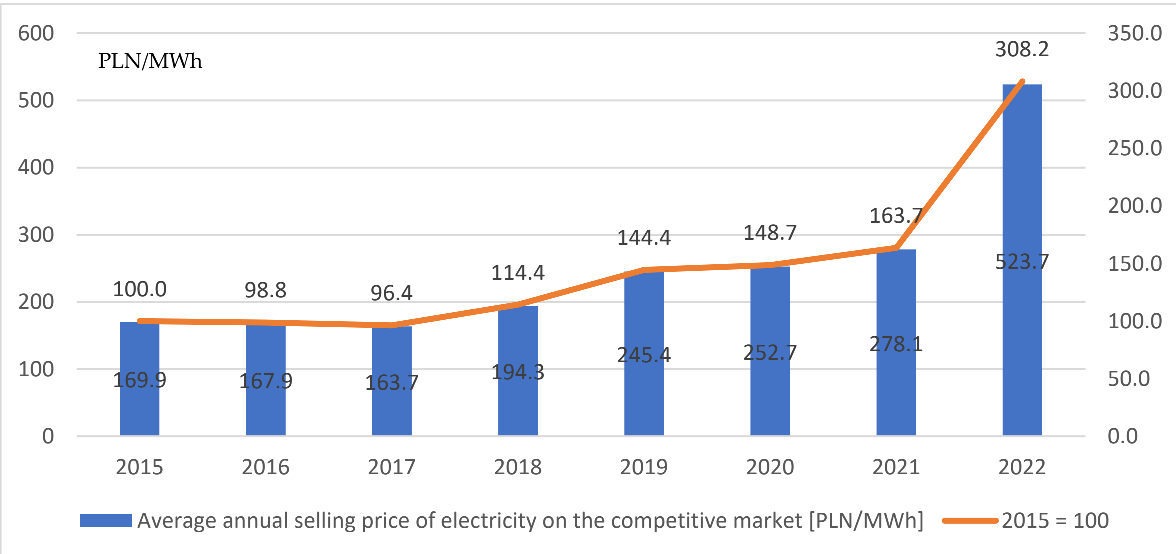

Figure 8. Average annual selling price of electricity on the competitive market [PLN/MWh]. Source: own calculation based on [79].

The average net price of electricity for individual customers in the years 2015–2019 remained at a similar level of about PLN 0.5/kWh. In subsequent years, an increase in the price of electricity was recorded, and in 2022 it amounted to nearly PLN 0.79/kWh. This is a 45.4% increase compared with 2015 (Figure 9). In 2023, the current electricity price for households was maintained at the average electricity price from 2022 as part of the so-called "anti-inflation shield". The net electricity price of PLN 0.79/kWh covers all households whose energy consumption does not exceed 3000 kWh. If this limit is exceeded, the net purchase price of energy for households rises to 1.22 kWh. In 2024, the price of eclectic energy for households approved by the Energy Regulatory Office will range from PLN 1.66 kWh to PLN 2.09/kWh [79]. In the case of households, the only reasonable solution that can reduce the costs associated with the purchase of electricity is their own photovoltaic micro-installation and optimization of the self-consumption level. The current and planned level of electricity prices means that the profitability of already existing and new photovoltaic projects is rising. The payback period is becoming shorter and the NPV and IRR of this type of projects are increasing. According to the Polish Economic Institute, depending on the technology chosen and the variant of the construction of a renewable energy plant, the current cost per kWh varies from PLN 0.12 to PLN 0.17, while the cost of a coal plant is about PLN 0.50 [85].

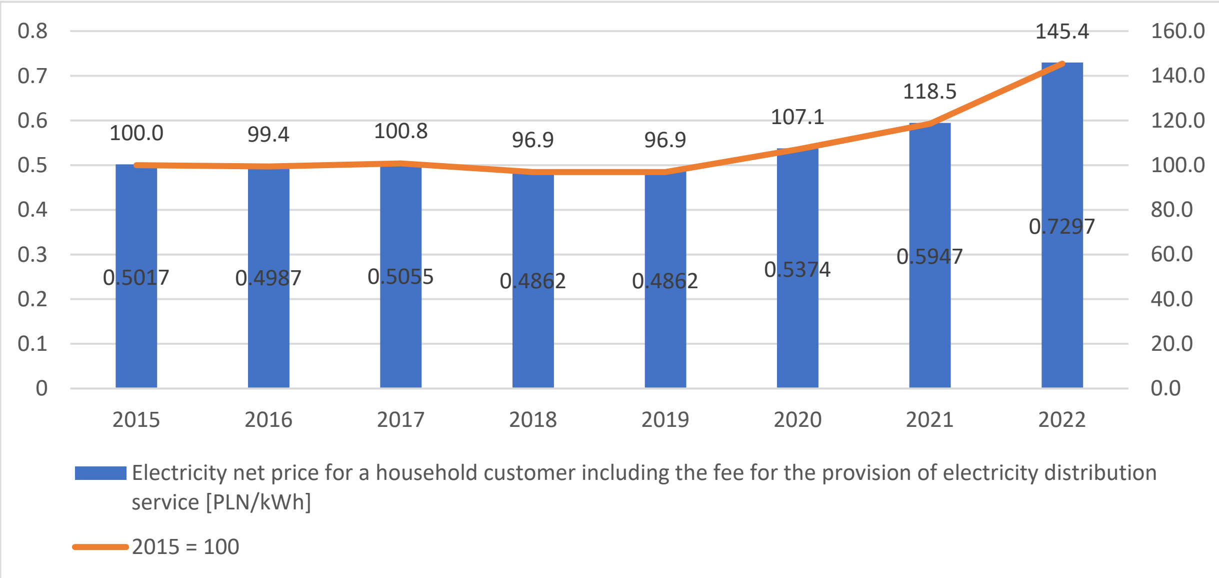

Figure 9. Electricity net price for a household customer including the fee for the provision of electricity distribution service [PLN/kWh]. Source: own calculation based on [79].

An important factor in favor of further expansion of photovoltaic capacity in Poland is the cost of construction and installation of such projects. The average cost of purchasing a photovoltaic installation in Poland is about PLN 5300/kWp (the price includes all costs of connecting to the network) [77], and this price has not changed in recent years. The average power of installed photovoltaic micro-installations in Poland is 5.8 kWp, which, given the unit price, makes the cost of such an investment relatively low and accessible to individual and institutional investors. In addition, the prices of raw materials necessary to produce photovoltaic panels on world markets are steadily declining as the prices of electricity in Poland continue to rise. This translates into an increase in the profitability of this type of investments.

PV energy is perceived as crucial to Poland's energy security, climate goals and jobs. Prices for renewable energy technologies are dropping rapidly, e.g., the cost of electricity from solar power fell by 85% between 2010 and 2020. The technology of obtaining solar energy not only brings multidimensional economic benefits and is environmentally friendly, but this technology, thanks to a relatively short investment cycle, provides a chance for a dynamic increase in new RES generation capacities in the system. In turn, ensuring adequate generation capacity significantly reduces the risk of energy shortages and contributes to lowering and stabilizing electricity prices. In addition, energy from photovoltaics and other renewable sources can reduce a country's demand for energy imports, and thus its dependence on other exporting countries. Renewable energy can therefore be considered the safest way to minimize the risks associated with energy supply by using energy that will be produced locally.

Photovoltaics can contribute to a breakthrough that would accelerate Poland's energy transition. Projections of the Institute of Renewable Energy in Poland show continued rapid growth of the PV market in the coming years [77]. Moreover, the growth rate of the domestic market will be much higher than the rate forecast for the EU or the world. For example, according to the International Energy Agency and Marketsand Markets, the global annual growth rate of PV capacity in 2022–2027 will be more than 10% [17,86]. In Poland, in turn, the annual growth rate will reach at least 20% per year. Looking ahead to 2025, the Polish market will remain one of the largest and most dynamic PV markets on a global scale [77].

4. Conclusions

In recent years, the photovoltaic market in Poland has been developing at a rapid pace. Poland uses the huge potential it has due to its very convenient geographical location and favorable helioenergetic conditions. Thanks to maintaining current trends and financial investment support systems, it has the opportunity to continue its dynamic development while maintaining a high position among EU countries.

However, in Poland, the rapid development of photovoltaics may be hampered by changes in the law and a reduction in financial support. The key legal issue relates to changes in the way prosumers account for unused electricity, and the lack of solutions to support investment in backyard energy storage. Another constraint affecting the advance of photovoltaics is the poor state of electricity grids. Thus, in order to obtain more energy from various types of RES, the Polish energy economy should simultaneously expand transmission networks and storage infrastructure, as well as install state-of-the-art technologies in the power grid. Such measures would contribute to improving national energy efficiency. Accelerating work on these solutions would allow for a more dynamic development of RES, which would consequently translate into meeting EU targets and increasing Poland's energy security.

The photovoltaic industry is facing new challenges. Therefore, policy makers should offer incentives for the development of PV and the entire market of renewable energy sources. These can include, for example, the introduction of tax credits so that various owners and users of PV systems can better meet their needs. Further expansion of secure power grids and support for prosumer energy should also be pursued. Better education aimed at increasing knowledge of the energy sector's impact on the environment and climate, the possibilities of using renewable energy sources in the power industry and the role of prosumers are also of vital importance. This would facilitate the formation of environmental awareness and, in the future, greater willingness to switch to clean energy sources. The use of renewable energy sources, and in particular photovoltaics, is a good solution to both the growing demand for electricity and ecological issues.

Author Contributions: Conceptualization, D.S. and A.K.-M.; methodology, D.S. and A.K.-M.; formal analysis, D.S.; resources, A.K.-M.; data curation, D.S.; writing—original draft preparation, D.S. and A.K.-M.; writing—review and editing, D.S. and A.K.-M.; visualization, A.K.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

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