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Review

Current Status and Prospects for the Development of Renewable Energy Sources in the Agricultural Sector in Poland

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Abstract

In Poland, renewable energy sources (RESs) are becoming increasingly significant, also in the agricultural sector. Poland has committed to EU energy policies to achieve a 21% share of RESs in gross final energy consumption until 2030. The newest data from 2023 indicates that up to that time, it was 16.56%. The situation is slightly worse in transport, where a 6% share of RESs has been achieved, compared to 14%, which is the target for 2030. The agricultural sector plays a significant role in this transition, as it offers opportunities for bioenergy production, such as biogas and biofuels, derived from agricultural waste and residues, but also by giving a place for photovoltaic panels and windmill farms. While the progress made is evident, challenges persist. This review paper presents the current status and prospects for the development of RESs with particular emphasis on the share of the agricultural sector. To do this, desk research and a literature review have been conducted. The newest statistics have been presented. A significant opportunity for the development of RESs in agriculture lies in harnessing the potential of the raw material base for biogas production, as well as leveraging funding from numerous support programs. A significant opportunity also exists for the development of agrivoltaics. Creating a legal framework for the development of agrivoltaics, as well as creating equal opportunities for all RESs to obtain funding, is a challenge. A major identified challenge that must be addressed, in order to capitalize on the potential of Polish agriculture for the development of RESs, is increasing connection capacity and expanding and modernizing the energy system.

Keywords: renewable energy sources (RESs); biogas; photovoltaic; agrivoltaic; wind energy; bioeconomy; energy law; agriculture

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1. Introduction

Amid escalating climate change challenges and the urgent need for sustainable development, renewable energy has emerged as a central element of the energy transition—particularly within the framework of European Union legislation. Sweden, Germany, Denmark, France, Italy, Spain, Austria, Finland, and the Netherlands are leaders in energy transformation. Poland and Bulgaria, however, face significant challenges [1]. Agriculture, as one of the main sectors of the economy, has great potential to incorporate solutions related to renewable energy sources (RESs). In Poland, as in other countries, agriculture is one of the sectors of the economy that generates significant energy demand and, simultaneously, significant emissions of greenhouse gases (GHGs) [2]. Energy consumption in agriculture

is associated with various types of activities—from plant cultivation, through animal breeding, to processes related to the storage and processing of agricultural products. On the other hand, agricultural lands have much potential for the development of RESs, such as large areas for wind and photovoltaic farms, as well as large amounts of waste biomass and the possibility of cultivating energy crops [3,4]. It also happens that bioenergy production has a negative impact, such as the production of bioethanol negatively influencing food production and causing an increase in water consumption and pollution [5].

The use of renewables can bring benefits both to the agricultural sector itself and to the whole of society, reducing the negative impact of agricultural activities on the natural environment. However, the introduction and development of RES technologies in agriculture also encounter numerous challenges. These include both technological and economic limitations related to investment costs and specific conditions in rural areas. On the other hand, agriculture can be one of the responses to the need to decarbonize the economy and increase energy efficiency. Modern technologies enable the production of renewable energy in a way that not only improves the sustainability of farms but also creates new sources of income for farmers. Poland is close to the average for the European Union (EU) in terms of renewable energy use in agriculture of 15%. Nonetheless, countries such as Germany, Austria, and Sweden exhibited much higher results, due to more developed infrastructure, especially biogas plants. Nevertheless, Poland is seeing dynamic growth in photovoltaics and interest in agricultural biogas [6].

According to a study of Hernandez-Escobedo et al. [5], the relationship of RESs with agriculture will be one of the most important goals of nations, and Poland is the sixth country in the world in terms of the number of research articles and publications related to renewable energy and agriculture in 2019–2021. The awareness of the great importance of agriculture for the development of RESs in Poland, as well as the scarcity of comprehensive reports on the opportunities and constraints for the development of RESs in this sector, prompted the undertaking of a review study. Dynamic changes in the energy market create the need for continuous updating of existing review articles. This study aims to present the current status of Poland's energy market and national policies, as well as discuss both the possibilities of integrating various RESs in agriculture and the barriers that need to be overcome for this sector to fully exploit its potential in the face of contemporary energy and ecological challenges. This paper focuses on the agricultural sector, which plays an important role in energetic transformation in Poland; however, there is a lack of comprehensive and current studies on this issue. The present study aimed to fill the gap in comprehensive data reports on the up-to-date state, opportunities, and threats in the development of RESs in rural areas.

2. Research Methodology

This study employed desk research and a literature review method. The desk research method was used to evaluate the current status of Poland's energy market and policies regarding RESs and the agriculture sector, as well as to identify opportunities and difficulties for further development of RESs in the agricultural sector. This involved reviewing statistics, government documents and strategies, scientific publications, and national and international reports. The searched websites were mainly gov.pl, ec.europa.eu, iea.org, ourworldindata.org, are.waw.pl, and statista.com. To search relevant references, the Scopus, WoS, and Google Scholar databases were used. Keywords we used were 'Poland' and 'renewables', 'renewable energy', 'agriculture', 'biogas', 'photovoltaic', 'agrivoltaic', and combinations of them. Moreover, we have narrowed the search area to 2023–2025. As regards agrivoltaics, which is a new topic in Poland, we also searched for information about it on websites such as wnp.pl, agrowoltaika.org, and globenergia.pl.

3. Poland's Agriculture and Energy Landscape

Polish agriculture is the fifth largest in the EU, behind France, Italy, Spain, and Germany. In 2020, the gross production value (GPV) and gross value added (GVA) of Poland's agriculture were EUR 26.7 billion and EUR 11.7 billion, respectively. In 2022, agriculture contributed around 2.2% to the gross domestic product (GDP) of Poland. Agricultural lands consist of 60% of the country's total area. Polish agriculture is characterized by fragmentation: slightly over half of the farms (51%) are smaller than 5 hectares, while only 5.2% exceed 30 hectares in size. Plant cultivation and livestock contribute 40% and 55% of the total agricultural production (by value), respectively [7].

Agricultural land is primarily used for the cultivation of wheat, barley, oats, potatoes, rapeseed, vegetables, and fruit. This provides significant opportunities for the development of a bioeconomy and RESs based on this biomass [8,9].

In 2024, the total energy consumption in Poland was 1118 TWh. The highest share of energy consumption was for coal and oil (Figure 1) [10]. The share of renewable energy in primary energy in 2024 was 13.1% and it sharply increased in recent years, mainly due to the change in the definition of small installations (i.e., the increase in the upper limit of range of power to 1 MW); (Figure 2) [10]. The share of RESs in gross final energy consumption was 16.56% in 2023 (of which 25.8% was in electricity, 6.0% was in transport, and 20.4% was in heating and cooling) [11].

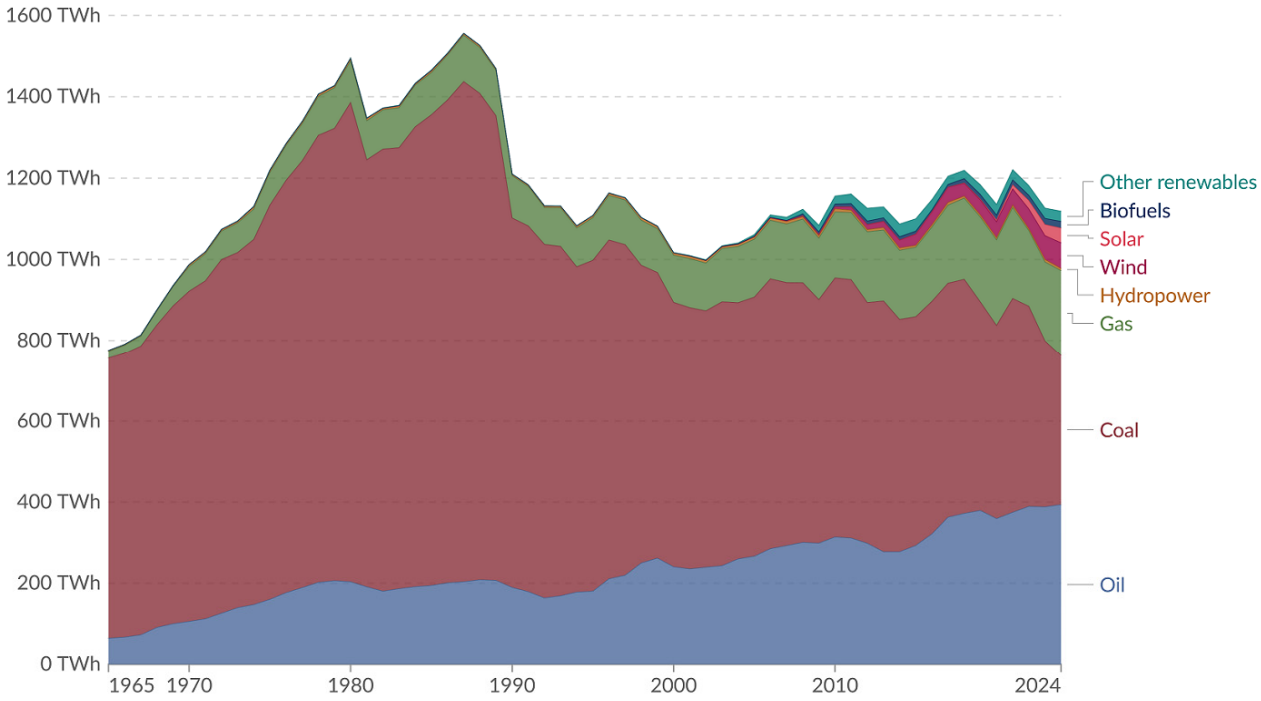


Figure 1. Primary energy consumption by source in Poland [10].

Thanks to Polish government support and strong consumer interest, Poland has become one of the fastest-growing rooftop solar markets in Europe. The government has introduced a well-designed and ambitious offshore wind program and is planning to build its first nuclear reactor by 2033 [12].

Regarding electricity production, the newest data shows that approximately 168.383 TWh was produced in Poland in 2024 [13]. Poland remains the European Union's most coal-dependent country; however, many efforts have been intensified to reduce the reliance on fossil fuels. The share of coal in the energy mix systematically decreased from 71.1% in 2022 to 56.7% (the sum of hard coal and lignite) in 2024, and from RES, it was 29.9% (Figure 3) [13].

It is visible in Figure 3 that photovoltaic and wind energy complement each other perfectly throughout the year and that biomass and biogas are very stable, although still an underdeveloped energy source.

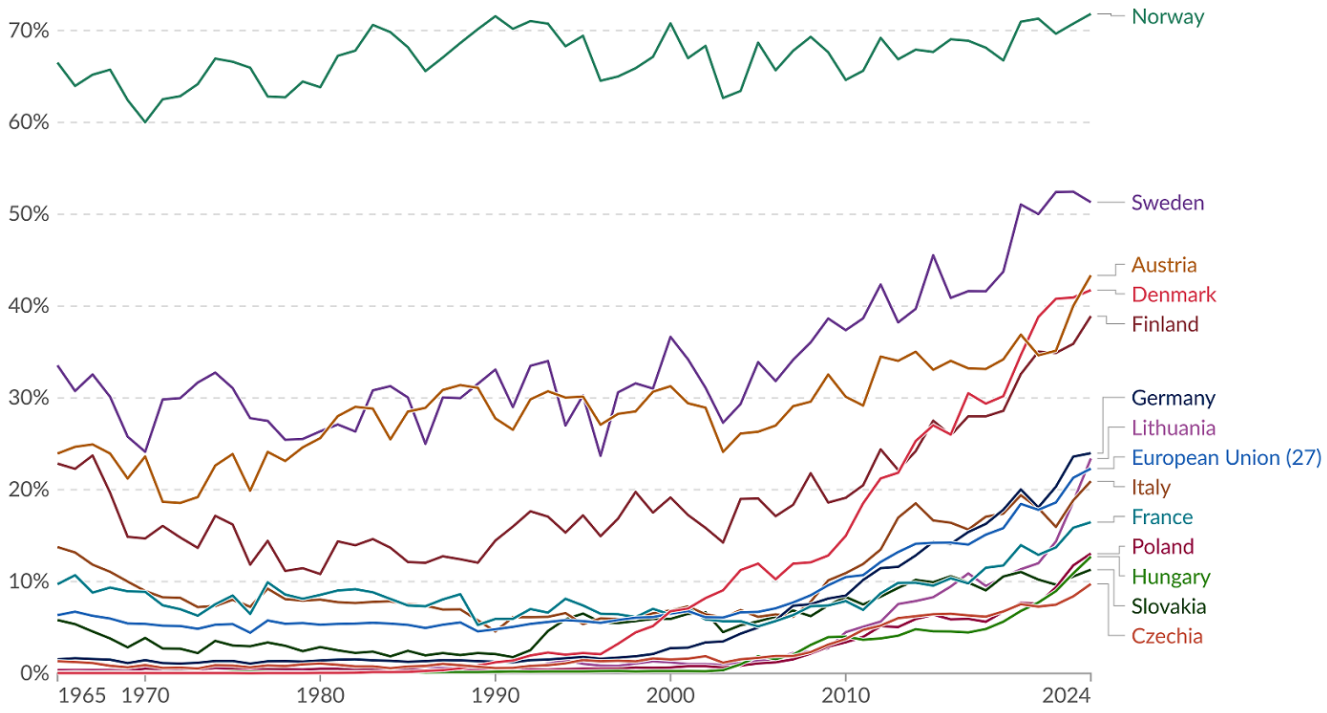


Figure 2. Share of renewable energy sources (RESs) in primary energy consumption in Poland compared to other countries and EU-27 [10].

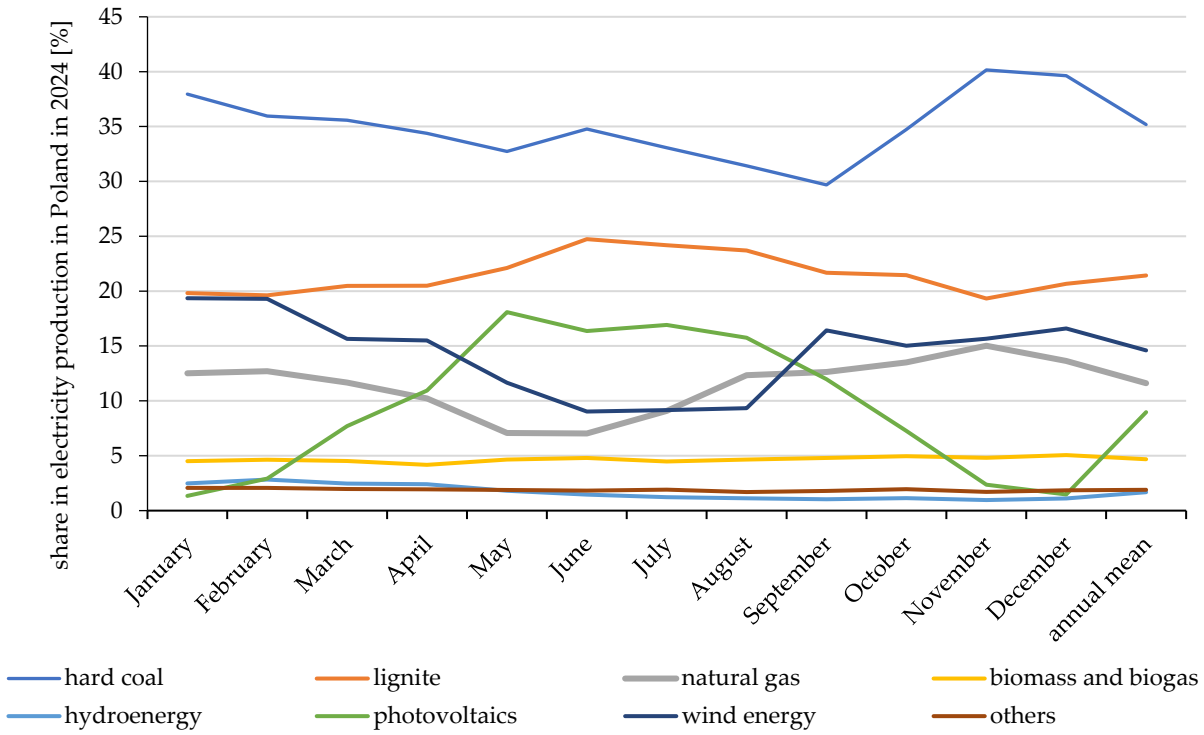


Figure 3. Electricity production in Poland is divided into sources (share in %) and months in 2024 (own study based on data from Energy Market Agency of Poland (ARE) [13]).

As regards primary energy production from renewables, the most used renewable sources were solid biofuels (60.1%), wind energy (15%), liquid biofuels (7.7%), and solar

energy (7.5%) (Figure 4) [14]. There is an almost inverse proportion between these sources in the case of electricity production. Most renewable energy carriers in electricity production come from wind energy (51.2% of total renewables), solar energy (23.5%), and solid biofuels (13.5%). Nonetheless, the importance of photovoltaic cells increased 27 times from a share of 1% of total renewables in 2018 to 23.5% in 2023 (Figure 5) [11].

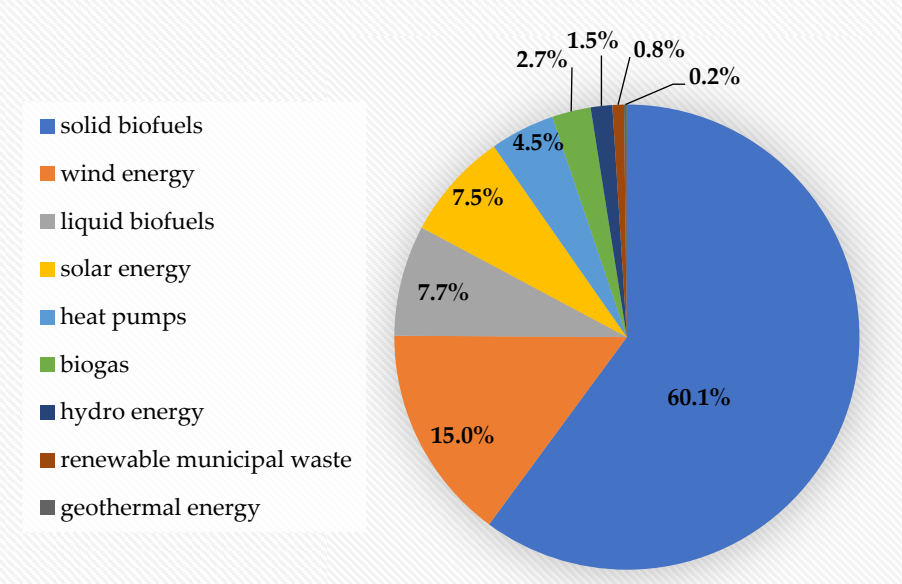


Figure 4. The share of renewable energy sources (RESs) in total primary energy production from RESs in Poland in 2023 (own study based on Statista [14]).

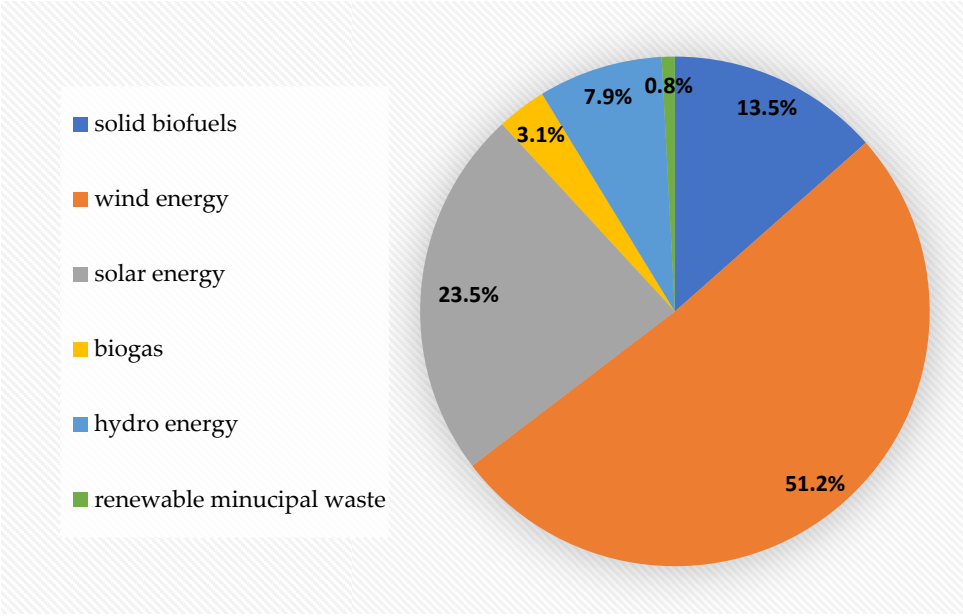


Figure 5. The share of renewable energy sources (RESs) in electricity production in Poland in 2023 [11].

Since 2017, most of Poland's energy consumption is related to transport (33% of total final energy consumption in 2023), followed by the residential (27%) and industrial (18.9%) sectors (Figure 6) [9]. The net primary energy consumption in agriculture in Poland was 148.8 TJ in 2023, which was only 4.9% of total energy consumption. The most important energy carrier used in agriculture is oil and petroleum products (64.4%). Therefore, there was a significant 17.8% drop in the consumption of solid fossil fuels in the agricultural

sector [15]. Energy produced out of renewable and biofuels accounted for 15.5% of the total energy consumption in agriculture (Figure 7) [16].

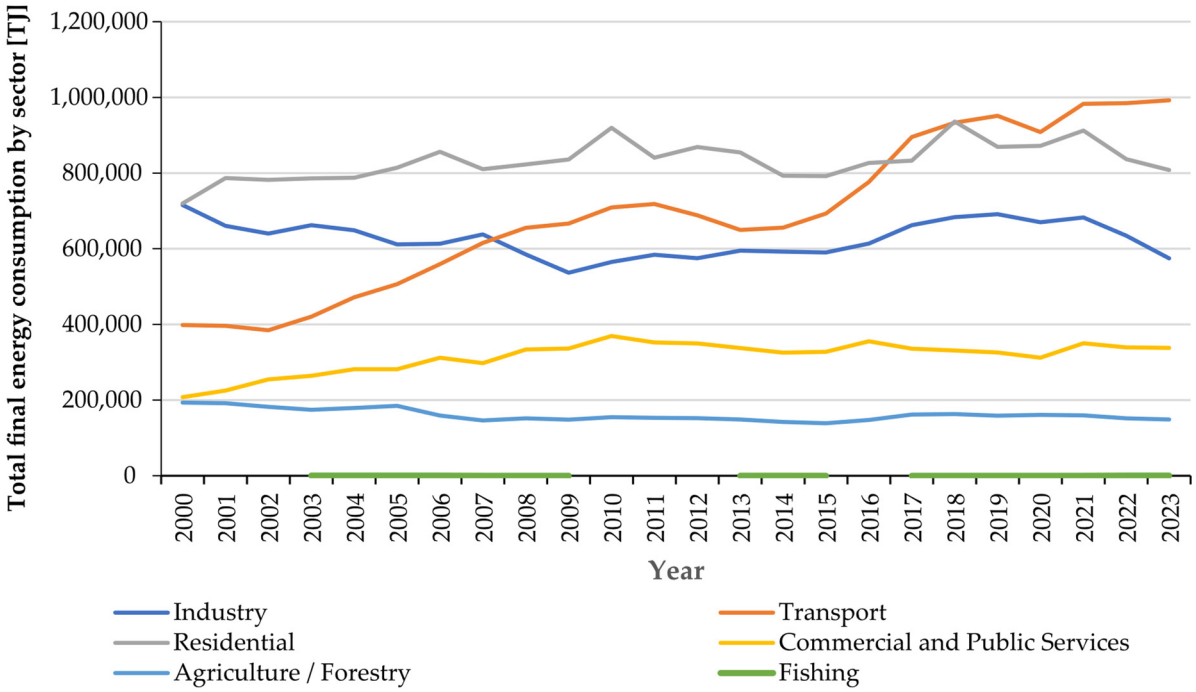


Figure 6. Total final energy consumption by sector in Poland from 2000 to 2023 (own study based on data from International Energy Agency (IEA) [9].

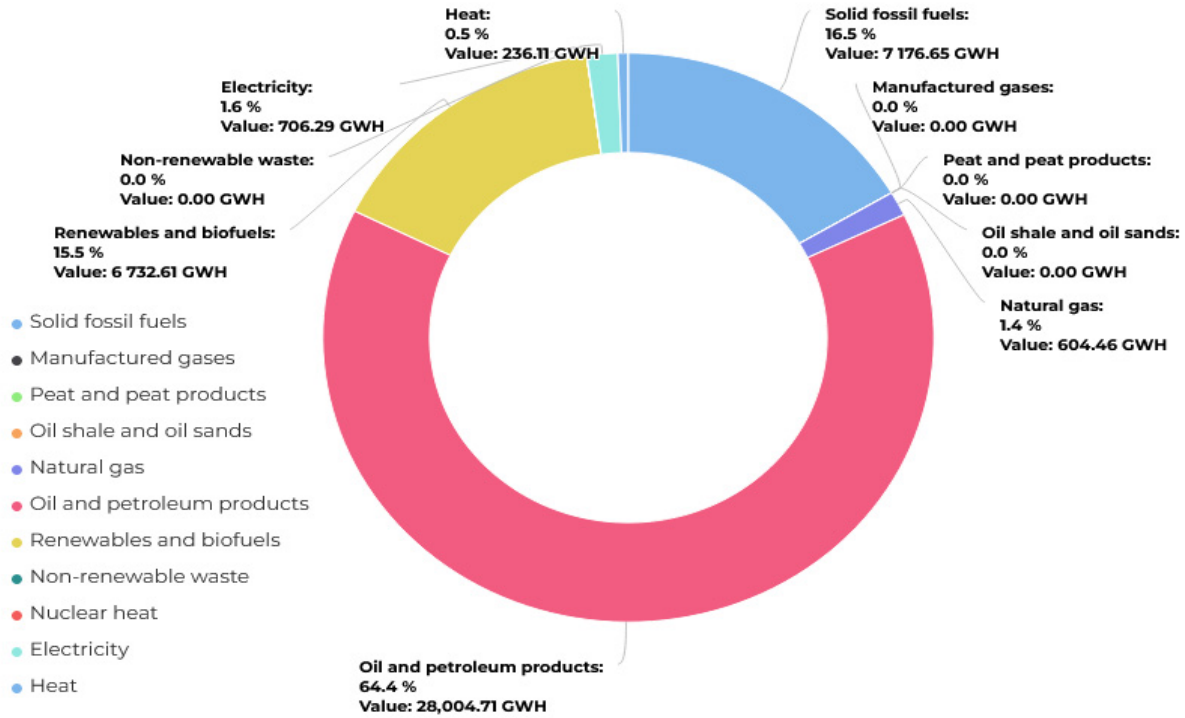


Figure 7. Energy consumption in agriculture divided into energy sources in 2023 [16].

The current situation of the energy market in Poland presented above, while offering significant opportunities for the development of RESs in agriculture, for example, the growing profitability of prosumer and local energy, also reveals many systemic barriers that require addressing.

Poland Compared to Other European Union Countries

Poland has been consistently developing its RES sector for over a decade, but compared to other European Union countries, this progress is still too slow. Despite the dynamic development of some areas, such as prosumer photovoltaics, Poland is still below the EU average in most key parameters of RES development.

The share of renewable energy sources in Poland's primary energy consumption currently stands at around 13.05%, while the EU average exceeds 22.29% (Figure 2). By comparison, Sweden, thanks to its extensive use of biomass, hydropower, and biofuels, achieves over 50%, while Denmark and Austria maintain figures above 40%. Poland thus ranks near the bottom of the rankings, primarily due to the high share of fossil fuels in the energy mix, particularly in the heating and electricity sectors [10].

In terms of the share of renewable energy in gross final energy consumption, Poland has reached approximately 16.56% in 2023, while the average for the European Union was 24.55%. Poland is still behind leaders such as Sweden (approx. 66.39%), Finland (approx. 50.75%), and Denmark (approx. 44.40%). These countries' high results stem from consistent support for all forms of renewable energy: in power generation, heating, and transport. Poland focused primarily on photovoltaics and partially on wind energy, neglecting other sectors [17].

As regards the share of RESs in the agricultural sector, this parameter for Poland (15.5% in 2023) does not differ much from the EU average, but it is lower than in Germany (22%), Austria (32%), and Sweden (36.4%), where biogas installations or agro-PVs are widely used [6,15].

One of the most critical indicators remains the share of coal in electricity production. In Poland, it still stands at around 60%, making us one of the most coal-dependent countries in Europe. By comparison, in Germany, this share has fallen to around 25–30%, and in Austria, Sweden, and Norway, it hovers around zero. Poland's heavy reliance on coal not only burdens the environment but also limits the potential for rapid expansion of RESs in the energy mix [10].

When it comes to the share of renewable energy in transport, Poland also remains below the EU average. In 2023, it stood at 6%, while the EU average is around 10%, and the 2030 targets envisage an increase to at least 14% [18]. Sweden is achieving as much as 30% thanks to the use of advanced second-generation biofuels. Finland, Austria, and the Netherlands have also exceeded 15–20%. Poland, on the other hand, is just beginning to develop electromobility and the production of advanced biofuels, and the lack of a coherent strategy for this sector hinders the achievement of EU targets.

Despite the above difficulties, Poland can be seen as a leader in one very important area, the development of photovoltaic prosumers. Thanks to financial programs, Poland already has over 1.4 million solar PV installations. This puts Poland among the EU leaders in terms of the number of households generating energy for their own needs. This model of citizen engagement in the energy transition could be an inspiration for countries like the Czech Republic, Slovakia, and Lithuania.

In summary, Poland faces many challenges, particularly in reducing the share of coal, developing RES in transport and heating, and supporting renewable energy investments in rural areas. At the same time, it can serve as an example in terms of social activation and simple mechanisms to support prosumption. Poland can learn from more advanced EU countries, such as Denmark, Sweden, and Austria, about an effective energy mix, sectoral integration, and effective long-term policies.

4. National Policies

In Poland, there is no single, comprehensive, and strategic document dedicated to RES development, let alone its development in rural areas. The implementation of policies supporting renewable energy sources (RESs) in the agricultural sector in Poland is based on a set of strategies, programs, and financial instruments, encompassing both the EU framework (Common Agricultural Policy—CAP) and national strategic documents, such as the Polish Energy Policy until 2040 (PEP2040); Strategy for Sustainable Development of Rural Areas, Agriculture, and Fishers 2030; and the National Energy and Climate Plan (NECP). Based on all the above strategies, many financial instruments have been developed to support RES development in the agricultural sector. Key financial mechanisms, including the "Agroenergy" and "Energy for the Countryside" programs, were implemented by the National Fund for Environmental Protection and Water. Below, a timeline is presented that organizes the main policies in the order in which they were implemented (Figure 8).

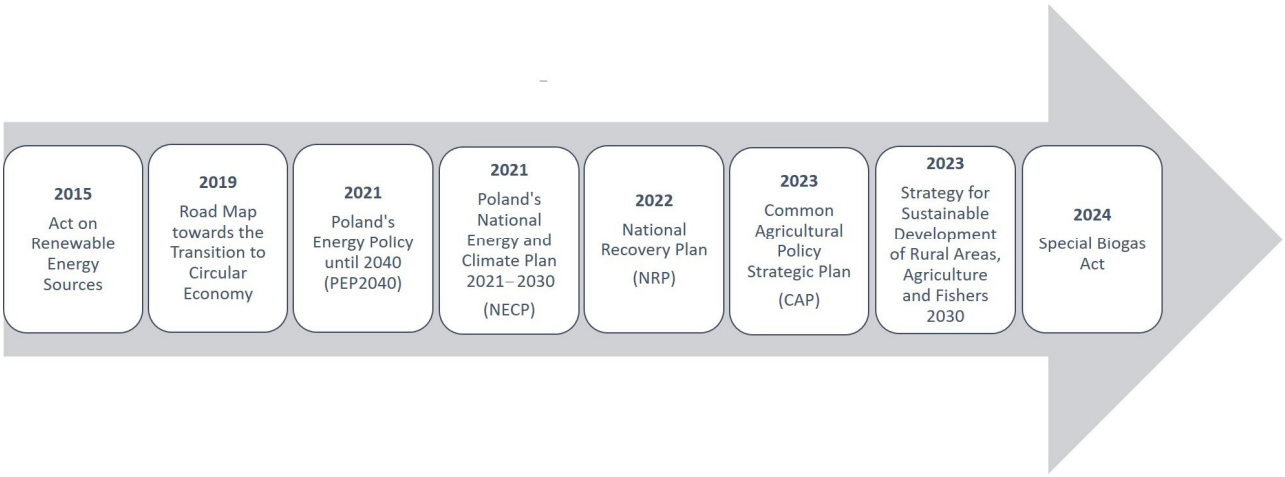


Figure 8. The timeline for implementing policies related to the development of renewable energy sources (RESs) in the agricultural sector.

4.1. Act on Renewable Energy Sources

Adopted on 20 February 2015, the Act on Renewable Energy Sources marked a breakthrough in Polish energy policy by creating a comprehensive legal framework for the development of RESs [19]. The main objective was to implement EU directives and increase the proportion of renewable energy in the national energy mix. The legislation set out the rules governing the renewable energy market and the financial support systems for producers, as well as the technical and organizational regulations for developing micro-installations, biogas plants, photovoltaic farms, and wind farms. A key element of the law was the establishment of investment support mechanisms for renewable energy sources. Initially, guaranteed tariffs (feed-in tariffs) and an auction system for larger installations were introduced, followed by the expansion of solutions supporting prosumer energy. The law also introduced administrative simplifications, including exempting micro-installations mounted on existing structures from the need to obtain building permits. Connection procedures have also been significantly shortened. The RES catalog was expanded to include biomethane, agricultural biogas, geothermal energy, and other sustainable energy sources. A legal basis was also established for operating guarantees of energy origin, a system that confirms the environmentally friendly source of electricity.

Following the law's implementation, the market for micro-installations, particularly photovoltaic systems, experienced rapid growth. According to 2023 data, Poland had over 1.2 million prosumers, making it a leader in distributed energy development in Central

and Eastern Europe. The law also increased public involvement in the energy transition by forming energy clusters, energy cooperatives, and energy communities, especially in rural areas.

Institutionally, the law introduced mandatory registries of RES producers, certification systems, and compliance with European Union (EU) regulations on state aid and sustainable development. In practice, this meant Poland was better prepared to meet the European Union's climate goals and gain access to national and EU funds to support green energy.

Despite these achievements, the act had its limitations. The main objections were the overloading of the electricity grid, which could not keep up with the rapidly growing number of prosumer installations, and the instability of the law, particularly with regard to billing systems.

4.2. Road Map Towards the Transition to Circular Economy

Poland participates in a macro-regional bioeconomy initiative, BIOEAST, being developed by Central and Eastern European countries. The national Bioeconomy Strategy Concept Paper is developed in the framework of the BIOEAST National Platform and the BIOEASTsUP project, coordinated by the Institute of Soil Science and Plant Cultivation (IUNG). Poland's Council of Ministers adopted the Roadmap towards the Transition to the Circular Economy [20]. The roadmap is a strategic document that determines the necessary actions to be taken by the public administration in order to establish a framework for a circular economy. The bioeconomy is one of the pillars of this roadmap, with tasks to be carried out by the government for bioeconomy development. This document has a strong link to RESs in agriculture, as RESs are an important element of the transformation towards a more sustainable and efficient economic system. Circular economy aims to maximize the use of resources through reuse, recovery, recycling, and waste minimization. The development of RES in agriculture can be a tool for circular economy by using postharvest waste biomass for biogas production or digestate as fertilizer, as well as combining food and energy production in the case of agrivoltaic systems.

4.3. Poland's Energy Policy Until 2040 (PEP2040)

PEP2040 acts as a guide for businesses, local governments, and citizens in transforming the Polish economy to become more environmentally friendly [21]. In PEP2040, strategic investment decisions are made to take advantage of the potential of the nation's economic, feedstock, technological assets, as well as labor force to create a lever for economic development, through the energy sector, fostering an equitable transformation.

By 2040, over half of the installed capacity will come from carbon-free sources. The implementation of offshore wind energy and the launch of a nuclear power plant in the Polish electricity system will play a special role in this respect. These will be two new strategic areas and industries to be developed in Poland. This will create opportunities for the development of domestic industry and specialized human resources, as well as generate new jobs and added value for the country's economy. Alongside this, local capital will drive the development of two other forms of energy: distributed and civic. The transformation also demands greater use of RES technologies in heat production and an increase in the deployment of alternative fuels in transport, including the development of electric and hydrogen-powered vehicles.

As regards agriculture, PEP indicates the potential of agricultural biogas plants, photovoltaic installations, and wind energy in agriculture. The policy encourages distributed energy, where households can act as prosumers. The summary of the plan's goals and the current status of their implementation is presented in Table 1.

Table 1. The summary of the goals of Poland's Energetic Policy 2040 (PEP2040) and the status of their achievement (own study based on the data from Ministry of Climate and Environment Republic of Poland and The National Centre for Emissions Management (KOBiZE) [21,22]).

PEP2040 Target	Target Value	Current Status	Progress Summary
Share of RESs in gross final energy consumption (FEC)	At least 23% in 2030	16.56% in 2023	Raised by still far to the goal
Share of renewable energy sources (RESs) in the electricity sector (power plants)	Approximately 32% in 2030	25.8% in 2023	The target has been almost achieved
Share of RESs in transport	14%	6% in 2023, but lower than 2022	Significantly off target
Share of RESs in heating/cooling Annual RES growth in heating/cooling	28% +1.1 pp per year	20.4% RES in heating in 2021 Annual growth c.a. 1–1.5 pp	On track
Offshore wind energy	5.9 GW by 2030, 11 GW by 2040	Just the beginning, no operating farms (0 GW)	Significantly off target
Photovoltaics (PVs)	5–7 GW by 2030 10–16 GW by 2040	Approximately 20 GW achieved in 2024	A target exceeded many times over
Nuclear energy	First unit ~2033; ultimately 6 units	Construction is scheduled to begin in 2026, with the operating theater scheduled for completion around 2040.	In progress
Reducing greenhouse gas emissions	−30% by 2030 (vs. 1990) −90% by 2040	−34% by 2022 (vs. 1988)	The target has been achieved
Energy efficiency	Reducing primary energy consumption by 23% by 2030, from 118.6 Mtoe in 2007 to 91.3 Mtoe in 2030	Primary energy use was 93.3 Mtoe in 2023 decreased c.a. 21.3% vs. 2007	Good progress
Coal share in electricity generation	56–60%	<60% in 2024	Almost fulfilled
Discontinuation of coal burning in households	Cities by 2030, villages by 2040	Modernization programs started, in progress	In progress
Energy poverty	30% reduction by 2030	Subsidies and programs continue	Scale of reduction difficult to estimate
Energy storage and smart grids	Development of storage, hydrogen, and smart grids	Implementation at an early stage, investments started	In progress

4.4. Poland's National Energy and Climate Plan 2021–2030 (NECP)

The National Energy and Climate Plan (NECP) is a plan for achieving five objectives of the energy union, i.e., energy security; the internal energy market; energy efficiency; decarbonization; and research, innovation, and competitiveness [22]. The plan indicates the potential of agricultural biogas plants, photovoltaic installations, and wind energy in agriculture. Below, the summary of the plan's goals and the current status of their implementation is presented in Table 2.

Table 2. The summary of the goals of Poland's National Energy and Climate Plan and the status of their achievement (own study based on data from Ministry of Climate and Environment Republic of Poland, National Centre for Emissions Management (KOBiZE), and Central Statistical Office of Poland [22–24]).

NECP 2030 Target	Target Value	Current Status	Progress Summary
GHG emissions in non-ETS sectors	−7% vs. 2005	Emissions have risen since 2005. From 2013–2020 increase of c.a. 14%. Latest detailed data pending.	Not on track
Share of RESs in final energy consumption	21–23%	15.56% in 2023. Slight growth compared to 16.1% in 2021, but decreased compared to 16.8% in 2022.	Behind schedule It seems to be stagnation in recent years.

Table 2. *Cont.*

NECP 2030 Target	Target Value	Current Status	Progress Summary
Share of RESs in transport	14%	6% in 2023, but lower than 2022.	Significantly off target
Annual RES growth in heating/cooling	+1.1 pp per year	>20% RES in heating I 2021 Annual growth c.a. 1–1.5 pp.	On track
Energy efficiency vs. PRIMES 2007	Decrease by 23% in the use of primary energy, from 118.6 Mtoe to 91.3 Mtoe in 2030	Primary energy use was 93.3 Mtoe in 2023; decreased by c.a. 21.3% vs. 2007.	Good progress
Coal share in electricity generation	56–60%	<60% in 2024.	On track

4.5. National Recovery Plan (NRP)

In the National Recovery Plan (NRP), renewable energy sources (RESs) occupy an important place as part of the energy transition, encompassing the agricultural sector [25]. These investments form part of the broader objective of reducing the Polish economy's dependence on fossil fuels, enhancing energy efficiency, and curbing greenhouse gas emissions. Component A of the NIP, entitled 'Resilience and competitiveness of the economy', includes measures to develop green energy and reduce energy intensity, including at the farm level.

A key element in supporting agriculture in this respect is investment A2.2.2, which provides financial support for farmers to purchase and install RES installations and energy storage facilities. The program allows for the co-financing of photovoltaic installations, small wind turbines, heat pumps, energy storage, and intelligent energy management systems. To receive support, the installations must be used to meet the needs of the agricultural business, thereby increasing the energy self-sufficiency of farms.

Although the NRP was not solely dedicated to agriculture, it proved to be a significant catalyst for the development of RESs in rural areas. By 9 September 2024, the targeted capacity for onshore installations, such as photovoltaic panels and wind turbines, had been fully implemented, meaning that the plan had been 100% realized in terms of RES infrastructure.

As part of the support for so-called energy communities, 19 projects were subsidized in June 2025 to the tune of PLN 700 million to develop energy clusters and cooperatives. This is highly conducive to joint agricultural investments in RESs.

The National Agricultural Support Centre (NEB) maintains a register of cooperatives, which currently lists 108 entities with 603 installations and a total capacity of over 42 MWe, primarily photovoltaic.

4.6. Common Agricultural Policy (CAP) Strategic Plan

At the end of 2023, Poland presented its CAP Strategic Plan. One of its main goals is to reduce dependence on synthetic fertilizers and increasing energy production from renewable sources without compromising food production [26]. One of the strategic objectives is to contribute to climate change mitigation and adaptation, including by reducing GHG emissions and developing carbon sequestration, as well as promoting RESs. Among other measures, funding has been planned for on-farm investment in RESs and energy efficiency improvement. Assumed support under this measure will allow the implementation of 2342 projects related to investments in energy production from agricultural biogas or solar radiation. Under this intervention, it will also be possible to invest in systems to improve the energy efficiency of buildings used for farm activities, which will cover approximately 2111 agricultural holdings. The total number of supported farms will reach 4543, which is 0.31% of all farms in Poland. Furthermore, the scope of the above intervention is complementary to other programs. Investment activities in the

field of RESs, using wind, solar, and biomass for energy production, are also envisaged in other programs co-financed from EU and national funds, e.g., the FEnIKS Programme: My Electricity, Agroenergy, which should strengthen the fulfilment of energy needs in rural areas.

4.7. Strategy for Sustainable Development of Rural Areas, Agriculture, and Fishers 2030

The primary goal of this strategy is to promote the economic development of the rural areas, ensuring a long-term upturn in residents' income, while reducing socioeconomic and territorial disparities and enhancing the environment [27]. The planned measures until 2030 include the following:

- Helping small, medium, and large farms in sustainable development.
- Making more effective use of the agri-food sector's potential through developing the skills and competencies of its staff, as well as through the use of the most up-to-date production technologies and the application of digital innovation to create new products.
- Establishing Poland's position as a major player in global food markets, through the promotion of Polish food as high-quality and rooted in tradition, while adapting to changing consumer needs (e.g., the growing interest in organic food).
- Conducting agricultural and fishing production with respect for environmental protection principles and adapting the agricultural and food sectors to climate change, including the availability of water.
- Creating opportunities that improve the professional mobility of rural residents and their access to development and re-skilling, arising from the appearance of new economic sectors (such as bioeconomy).

RES development in the agricultural sector can help to achieve all goals mentioned above. The Strategy for Sustainable Development of Rural Areas, Agriculture, and Fishers 2030 treats the development of RESs in agriculture as a tool for modernization, increasing resilience to energy crises, and building a green rural economy. Key directions include biogas plants, photovoltaics, and prosumer energy, related to the circular economy.

4.8. Special Biogas Act

The Ministry of Agriculture and Rural Development prepared a special act (Act of 13 July 2023) to facilitate the investment process for agricultural biogas plants and their operation [28]. The primary goals are to streamline the preparation and implementation procedures, boost the utilization of local substrate resources, and optimize the management of digestate, which is now regarded as a valuable resource rather than waste. Provisions to speed up the granting of network connection conditions and to reclassify some substrates as byproducts are of particular importance to the industry.

5. The Greatest Opportunities and Difficulties

5.1. Opportunities

The development of RESs in Poland creates many opportunities for the agricultural sector, which can contribute to increasing its competitiveness, improving efficiency, and sustainable development. The incorporation of RES can lead to more resilient farming systems by decreasing dependence on external energy supplies, thus improving the overall energy security of rural areas.

5.1.1. Biogas and Biomethane

One of the renewables associated strongly with agriculture is biogas and biomethane, mainly due to agricultural substrates suitable for production. Farmers can use organic

waste (e.g., manure, plant residues) to produce biogas. Biogas plants can be not only a source of energy but also an additional way of managing agricultural waste, which brings ecological benefits. There is a particularly big problem with the huge amount of unmanaged manure, which emits methane, one of the greenhouse gases contributing to global warming. Profits from biogas production can be an alternative source of income for farms, especially in regions with intensive animal production.

At the end of 2024, Poland had a total of 442 biogas plants, including 174 agricultural, 195 municipal, and 73 micro-biogas plants, the latter of which produce energy for their use [29]. Total power of agricultural biogas plants is now ca. 165 MW. Due to the relatively high fragmentation of agricultural production in Poland, the installed capacity of most installations does not exceed 1 MW. The share of biogas in the overall structure of obtaining electricity from renewable sources is ca. 2.5%. According to data from the National Support Centre for Agriculture, total biogas production in agricultural biogas plants increased successively and was ca. 469 mln m^3 in 2024, which corresponded to 1012 GWh of electricity (Figure 9) [29].

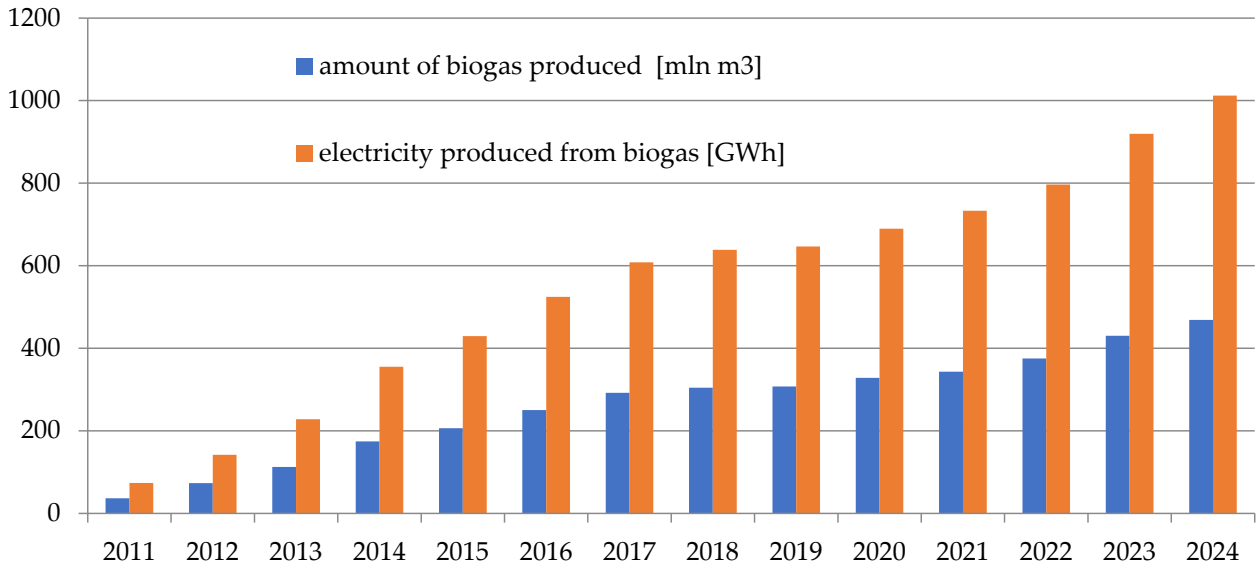


Figure 9. Production of biogas and electricity in agricultural biogas plants in 2011–2024 (own study based on data from National Support Centre for Agriculture) [29].

Over 7.5 million tons of substrate were used for this production. The composition of the feedstock in agricultural biogas plants in Poland has evolved over the years (Figure 10) [30]. In the early stages, corn silage and liquid manure were the dominant substrates. Since 2018, the most popular substrate was distillery decoction. Since then, the use of food processing waste has also increased significantly.

As regards biomethane, many installations for biomethane production are now in preparation. The first biomethane plant in Poland was built as part of the "Innovative Biogas Plant" competition organized by the National Center for Research and Development and the Poznań University of Life Sciences at the experimental station in Brody. The development of innovative technologies for the biogas, biomethane, and digestate sector has been supported by the National Center for Research and Development, which has implemented specific initiatives with European funds under the Smart Growth Program. Based on the amount of biomass in Poland, it is estimated that the potential for biogas and biomethane production is 15 and 8 billion m^3 per year, respectively.

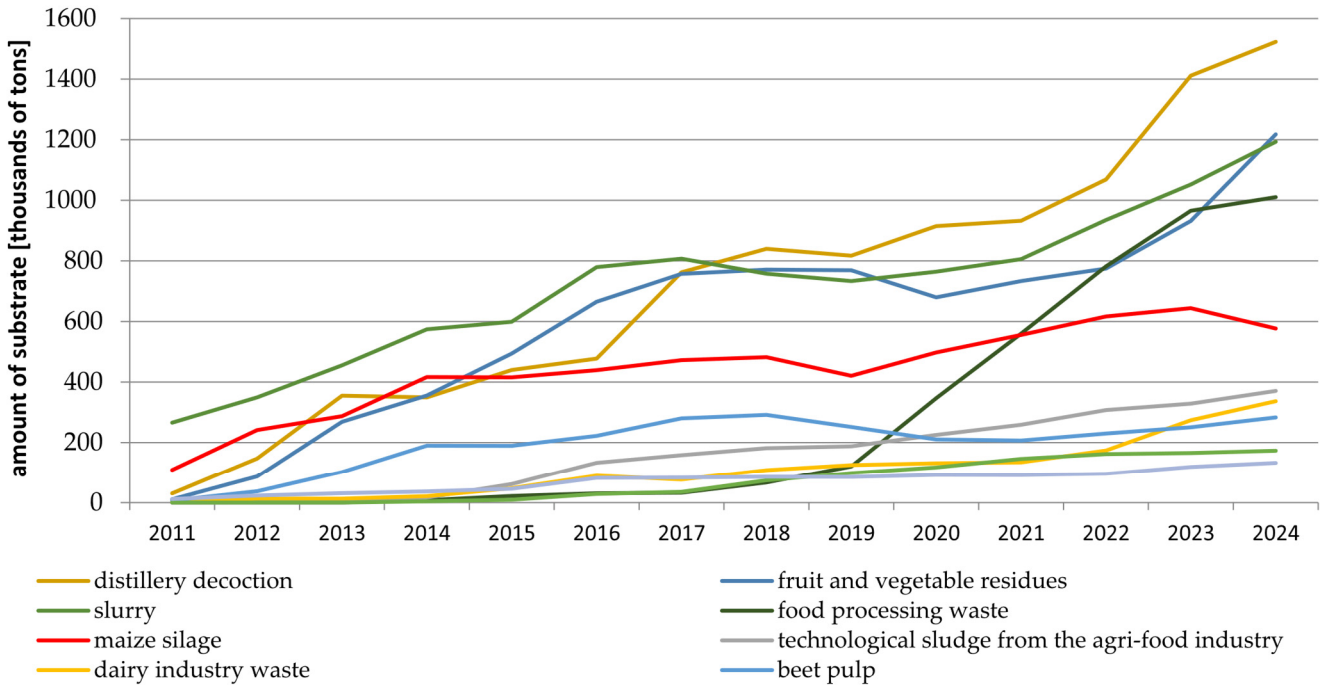


Figure 10. Changes in the kind and quantity of substrates used for agricultural biogas production from 2011 to 2024 (own study based on data from National Support Centre for Agriculture [30]). The substrates consumed in the largest quantities are presented on the graph.

Digestate Production

In Poland, digestate can be used as fertilizer once it meets the minimum criteria for fertilizing components and organic matter, while also adhering to limits on impurities (heavy metals, pathogenic organisms, and parasite eggs). Until 2023, the third group of fertilizer preparations, along with fertilizers and plant growth promoters, now includes post-digestion products, which have the same legal status. Consequently, when produced from designated secure substrates, digestate is not required to undergo a sophisticated process before being offered for sale [31]. This simplifies the management of large quantities of digestate (over 4.3 million tons) for biogas producers.

5.1.2. Photovoltaics and Agrivoltaics

Farms, especially those with large areas, can invest in photovoltaic technology, which allows them to produce electricity for their use, and surpluses can be sold to the grid. Photovoltaics is one of the fastest-growing parts of renewable energy sources in Poland. Nonetheless, the growing demand for solar energy is leading to competition for land, which can cause economic, ecological, political, and social conflicts [32]. Agrivoltaic (APV) technology provides a solution to these problems by enabling the simultaneous production of food and energy on the same land, increasing land use efficiency. APV technology was developed as a solution to the growing competition for land between food and energy production. Agrivoltaics have many advantages, such as protecting plants from heat or increasing the efficiency of the panels, thanks to the presence of plants. Plants growing under the photovoltaic panels are protected from the most intense sunlight, and by giving off water vapor, they cool the photovoltaic panels from below, which increases their efficiency [33]. The disadvantage of such installations may be the limitation of agricultural activities using large machines [34].

Unfortunately, currently in Poland, there is no suitable agrivoltaic regulatory environment, which would provide for dual use of land. It is the main barrier to the development

of agrivoltaics in Poland. An amendment to the law on spatial planning is needed to add the possibility of dual land use and to eliminate the requirement to exclude land from agricultural production for agrivoltaics. This amendment would allow for direct subsidies to be maintained and tax increases to be avoided. Unfortunately, for the time being, the installation of photovoltaic (PV) panels is possible only on land excluded from agricultural production [35].

There is the Polish Photovoltaics Association in Poland, which includes a special group for agrivoltaic issues. Moreover, agrivoltaic technologies are known in Poland, and there are also domestic companies that deal with their development. There are individual photovoltaic farms where sheep are grazed or flower meadows are established for bees. One of the first experimental agrivoltaic farms was established in Zgorzelec by the Zgorzelski Energy Cluster [36]. In 2022, wild garlic was grown there under panels with very good results, including high yields and improved growth conditions.

According to the report of the Joint Research Centre (JRC) from 2023, considering to use an average APV system with a power density of 0.6 MW/ha, the area required in Poland to reach the 2030 NECP photovoltaic capacity target of 30 GW, with only APVs, would be approximately 50,000 ha, which is 0.3% of the Utilized Agricultural Area (UAA), or 0.5% of arable land, or 1.6% of permanent grassland and meadow [37].

5.1.3. Biogas vs. Photovoltaics

Recent studies on investment profitability proved that photovoltaics are more profitable RESs than biogas. Kusz et al. [38] compared a few variants of biogas plants and stated negative net present value (NPV) for all of them. Internal rate of return (IRR) was also low, in the range from −3.07 to 7.05. It indicates that investments were unprofitable without a subsidy of approximately 40–60% of their value. On the contrary, the NPV and IRR for photovoltaics were much higher, although also in this case, the profitability depended on the type of investment, mainly its size [39].

Böhm et al. [40] stated that, also from an environmental point of view, biogas is less profitable than photovoltaics and wind. Nonetheless, such an analysis result could have been influenced by the fact that the authors analyzed the biogas obtained from maize, not waste and agricultural byproducts. Czekała et al. [41] proved that biogas plants operating on waste substrate are much more profitable and environmentally friendly than those processing maize silage.

5.1.4. Support Systems for Production of Renewable Energy

The European Union and the Polish national government offer various support programs and subsidies aimed at promoting the development of renewable energy sources within the agricultural sector. Thanks to these funds, it is possible to finance investments in renewable energy technologies by significantly reducing the high initial installation costs. The current catalog of financing and support mechanisms available in Poland for renewable energy investments includes the following:

- Investment subsidies for installation of renewable energy sources.
- Funds allocated at the central and local levels.
- Support from the National Fund for Environmental Protection and Water Management (NFOŚiGW) and its regional branches (e.g., programs “Agroenergy” 2019–2027, “Energy for the Countryside” 2022–2030, “Clean Air” 2018–2032).
- Preferential loans and credits granted by the banking sector.
- Large-scale investment loans (bank consortia) for the construction of power plants producing electricity from renewable energy sources.
- Public–private partnerships (PPPs).

- Leasing.
- Green bonds.
- Share capital.
- Tax incentives for individual users (including exemption from personal income tax and thermal modernization relief).
- Tax exemptions for renewable energy producers (VAT—Value Added Tax—and tax exemption excise duty) [42].

Table 3 presents a summary of the main financial programs supporting RES development in Poland.

Table 3. Characteristics of renewable energy support programs in Poland [39,43].

Program	Implementation Period	Goals	Funding Source	Budget
Agroenergy	2019–2025	Support for RES installations (PV, wind, biogas, heat pumps) for farms	NFOŚiGW	Over PLN 200 million
My Electricity	2025–2026	Support for PV micro-installations and energy storage for prosumers	NFOŚiGW/ FEnIKS	PLN 400 million
Clean Air Plus	2023–2028	Thermomodernization, installation of heat pumps, PV, collectors	NFOŚiGW/State Budget	approx. PLN 1.5 billion per year
Energy for the Countryside	2024–2027	Support for RES and prosumer energy in rural areas	ARiMR/FEnIKS	PLN 1.5 billion
My Wind Farm	2025–ongoing	Subsidies for small wind ($\leq$20 kW) and energy storage	NFOŚiGW/WFOŚiGW	Up to PLN 47,000 per installation
FEnIKS (RES Development)	2021–2027	RES and energy storage investments (biogas, PV)	EU/NFOŚiGW	PLN 376 million

Moreover, the current support system consists of Certificates of Origin (CoOs) (blue certificates for agricultural biogas and green certificates for other renewables); the auction system; Power Purchase Agreements (PPAs), which are lengthy energy provision agreements between a generator and its client or merchant; as well as support in the form of Feed-in Premiums (FiPs) and Feed-in Tariffs (FiTs) for biogas and hydropower only. The amount of support under FiPs and FiTs is determined by the reference prices announced each year by the President of the Energy Regulatory Office [44].

5.2. Difficulties and Challenges

The transition to RESs is not without its challenges. High initial costs for the installation of RES technologies remain a major barrier, despite the long-term economic benefits. The availability and accessibility of suitable technologies are still limited. No less important are also the predominance of small farms, insufficient knowledge about energy cooperatives, and reluctance to cooperate between farmers. Legal and regulatory barriers also play a significant role in slowing the adoption of RESs within the agricultural sector. Administrative and procedural difficulties in obtaining necessary permits, as well as inconsistent policy implementation at local and national levels, create a highly fragmented

regulatory environment. Most of the strategic documents presented above, such as the NECP, PEP2040, CAP, and NRP, declare converging goals, which include the development of RESs in rural areas, diversification of energy sources, energy transformation of agriculture towards low emissions, as well as supporting the circular economy. Despite the coherence of the goals, the degree of operationalization of these goals varies significantly. The documents do not always define clear coordination mechanisms, and some of them are declarative or too general. We can notice significant asymmetries and implementation gaps in the strategic documents and support mechanisms, which sometimes are inconsistent, causing different RESs to compete for the same funds. The technology of agricultural biogas is losing the competition with photovoltaics, despite obvious environmental and economic benefits, in the form of additional advantages from waste disposal and organic fertilizer production. Photovoltaics win the fight for grants primarily due to the ease of installing micro-installations on agricultural buildings, the lack of complicated environmental or infrastructural requirements, strong lobbying, and high social acceptance, as well as a shorter payback period and lower investment risk. On the other hand, biogas is a capital-intensive investment, primarily intended for large and medium-sized farms. Until recently, investing in biogas was also associated with numerous administrative barriers. Only the Special Biogas Act has realistically simplified the investment process. However, more significant effects of the Act will still take some time.

Despite the inconsistency, analysis of policies allows for the identification of certain gaps, e.g., the lack of legal and regulatory frameworks for the development of agrivoltaics. There is also a lack of systematic reporting on the effectiveness of the mentioned policies regarding energy transformation in rural areas, informing, for example, how many farms are energy-independent and how many struggle with insufficient access to adequate connection capacities. The problem also lies in the absence of a clear institutional leader in the development of renewable energy sources in agriculture. Various activities are dispersed among the Ministry of Agriculture and Rural Development (MRiRW), Ministry of Climate and Environment (MKiŚ), National Fund for Environmental Protection and Water Management (NFOŚiGW), and Agency for Restructuring and Modernization of Agriculture (ARiMR).

Moreover, many rural areas in Poland still lack the necessary infrastructure to efficiently transmit renewable energy, particularly in terms of grid capacity, flexibility, and regional connectivity. The existing power grid was not designed to accommodate the decentralized and variable nature of renewables such as wind and solar. As a result, delays in grid modernization and expansion hinder the integration of new RES projects, especially in regions with high generation potential but weak transmission infrastructure. The Institute of Renewable Energy in Poland reported as early as 2016 that even 70% of agricultural farms suffer from a deficit of electrical connection power (e.g., below 20 kW), which hinders the use of modern technologies or RES installations [45]. Moreover, 30% of farms had power connection capacities that were too low at that time to effectively develop agricultural production, which is particularly evident in regions with intensive mechanization [46]. The Energy Regulatory Office reports that energy companies have reported 7817 refusals to issue connection conditions to the electricity grid in 2024, with a total capacity of 73,586.12 MW. Among them, 4443 refusals were due to a lack of technical connection conditions (total connection capacity: 33,508.55 MW), and 2196 refusals were due to economic reasons (total connection capacity: 12,637.58 MW). In 1178 cases, the refusal was due to both a lack of technical and economic conditions (total connection capacity: 27,439.99 MW) [47]. An escalating problem is the excess supply of power compared to the transmission capacity of the grid and peak energy demand (150 MW of renewable energy already connected

and those that have already received connection conditions, compared to the peak energy demand in the system of about 25–26 GW).

Addressing these challenges will require substantial investment in smart grids, energy storage systems, and cross-regional interconnections, alongside regulatory support and long-term planning. This results in inefficiencies and creates hesitation among farmers to invest in RES systems, as they face uncertainty regarding grid connection and energy distribution. Most investments have focused on mature solutions such as onshore wind and photovoltaic systems, often without incorporating the latest technological innovations. As a result, the country is not fully capitalizing on the potential efficiency gains and grid-stabilizing benefits of modern renewable systems. Innovation in areas like offshore wind, geothermal energy, and biogas remains underdeveloped compared to other EU countries. A stronger focus on research and development, pilot projects, and local manufacturing capabilities is essential to enhance the performance, reliability, and cost-effectiveness of renewable energy technologies deployed in Poland.

5.3. Proposing Solutions to Improve RES Development

Many solutions have been presented, which have already been implemented for RES development in the agricultural sector in Poland. It seems that additional solutions are needed to further improve and accelerate it.

Coordinated legislative, financial, technological, and social actions are necessary. First of all, internal policy documents need to be simplified, and frequent changes—even to key legal acts such as the Renewable Energy Sources Act—should be avoided.

Moreover, simplification of administrative procedures is needed, i.e., shortening and simplifying the process of issuing permits for the construction of RES installations as well as reducing the number of required environmental agreements, especially for smaller projects.

To ensure a balance between the financing of all RES technologies and the effectiveness of the energy transformation of rural areas, it is necessary not only to increase the scale of support for biogas but also to better adapt it to the specific nature of this technology and to increase transparency and inter-institutional coordination.

The next solution, which can facilitate the creation of new RES installations, is modernization of the energy grid and investments in transmission and distribution infrastructure so that it can accept energy from RESs. Introduction of intelligent networks (smart grids) enabling better energy management and expansion of energy storage facilities (batteries, pumped-storage power plants, hydrogen) are also very needed.

Despite so many investment announcements, great potential, and needs, the biomethane market still does not exist in Poland. It seems that the reason may be the outdated gas network or its local deficiencies. Allowing produced methane to be transported directly to the recipient could also help to avoid this problem.

6. Conclusions

Poland is strategically committed to reducing its reliance on energy imports and enhancing the share of RESs within its national energy mix. The requirement of achieving a 21% share of RES in gross final energy consumption until 2030 is still realistic to meet. Nonetheless, we can observe a rather slow increase in this indicator in recent years, and even a slight decline between 2022 and 2023. Poland faces an even greater challenge in the transport sector. Hence, further development and efforts need to be sustained, and regulations need to be simplified to make them more transparent and supportive of further investments, also in the agricultural sector.

The energy sector in Poland actively participates in efforts to reduce greenhouse gas (GHG) emissions by gradually decreasing the share of coal in the energy mix and develop-

ing RESs. Within this context, the agricultural sector presents significant potential for RES integration, given its access to land, organic residues, and opportunities for decentralized energy production.

The implementation of RESs in agriculture, particularly photovoltaics, biogas, and biomass, offers substantial benefits, including reductions in operational energy costs, improved energy autonomy, enhanced resource efficiency, and meaningful contributions to climate change mitigation through a reduction in GHGs. However, the key to success is to select the right technologies for the specifics of the farm scale, regional climatic and environmental conditions, and local infrastructure, so it necessitates a context-specific approach.

Poland has achieved significant success in the development of photovoltaics, primarily thanks to the involvement of private farms, largely in rural areas. Numerous programs financed by both domestic and European sources have contributed to this success. At the same time, significant potential in Polish agriculture is associated with biogas production, due to the abundant resources of waste biomass and animal manure. To fully utilize this potential, dedicated support for this technology seems advisable, so that it does not have to compete with photovoltaics for the same funds. Another significant challenge is the lack of connection capacity, which prevents the development of renewable energy sources despite this significant potential.

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