Agnieszka BRELIK • Wojciech LEWICKI • Milena BERA • Monika ŚPIEWAK-SZYJKA

THE ESSENCE OF THE POTENTIAL OF THE AGRICULTURAL BIOGAS MARKET IN POLAND – A CASE STUDY OF A BIOGAS PLANT PROJECT

Agnieszka **Brelik** (ORCID: 0000-0003-0199-2040)
Wojciech **Lewicki** (ORCID: 0000-0002-8959-8410)
Milena **Bera** (ORCID: 0000-0002-1997-349X)
Monika **Śpiewak-Szyjka** (ORCID: 0000-0001-5527-0305)
– University of Technology in Szczecin, Faculty of the Economics West Pomeranian, Department of Regional and European Studies

Correspondence address:
Żołnierska Street 47, 71-210 Szczecin, Poland
e-mail: wojciech.lewicki@zut.edu.pl

ABSTRACT: In recent years, the development of renewable energy sources has become one of the key demands in the European Union's policy. In Poland, the idea emerged that the energy potential of domestic agriculture may be an opportunity for broader use of the available agricultural biomass. Given that agricultural biogas has long been seen as one of the most promising directions for energy transition, the goal of the article was to assess the potential of the agricultural biogas market in Poland. The research methodology was based on statistical measures related to analysing the structure and changes over time in individual years. The structure analysis was carried out for selected Polish provinces, for which empirical distributions were built and selected descriptive parameters were calculated. A similar study was made in relation to selected EU countries. In addition, according to the National Action Plan for Renewable Energy, at least one agricultural biogas plant should be established in each Polish municipality. On this basis, the article assesses the ecological effect of the project on agricultural biogas in Marcinkowice, in the Zachodniopomorskie Voivodeship. The presented simulations allowed us to conclude that an agricultural biogas plant can be an ecological potential in the form of reducing the consumption of fossil fuels by reducing emissions of pollutants and greenhouse gases into the atmosphere while reducing fossil fuel consumption. It was important for the practice to confirm that investing in renewable energy sources, including the use of biogas, is part of the goals and directions of development related to the sustainable management of environmental resources and the development of renewable energy sources.

KEYWORDS: renewable energy sources, biogas market, analysis, agriculture, case study, ecological and energy effects

No. 4(83) 2022 • pages: 196-214 DOI: 10.34659/eis.2022.83.4.492 JEL: Q20, Q42, Q50

Introduction

The available literature emphasises that the biogas market in Poland is an interdisciplinary issue covering technical and organisational aspects of legal and even economic and social nature (Drożdż et al., 2021; Pietrzak et al., 2021; Tucki et al., 2019). Many researchers combine this subject with landfill, sewage or municipal biogas. The amendment to the Energy Law Act made by the legislator on 8 January 2010 introduced the definition of agricultural biogas referred to as gaseous fuel (ACT, 2010). Therefore, the huge energy potential of domestic agriculture may constitute an opportunity for the dynamic development of this energy sector in Poland (Bielski et al., 2021; Lipiński et al., 2018; Szyba et al., 2022; Janiszewska, 2019). Available reports and studies indicate that the theoretical raw material potential of the available biomass is estimated in the range of 5 billion m^3 of biogas (Energy Regulatory Office, 2021). This potential presupposes the use, as a priority, of agricultural by-products, liquid and solid livestock manure and by-products and residues from the agro-food industry. At the same time, together with their use, the possible use of crops is also planned, including those referred to as energy crops, as a substrate for biogas plants. It is estimated that this effect can be achieved in an area of approx. 700 thousand ha, which will allow for full coverage of national food needs and obtaining additional raw materials necessary for the production of agricultural biogas and biofuels (Czerwiakowska-Bojko & Zmuda, 2009).

On the other hand, the actual available raw material potential of biogas production, contained in agricultural by-products and residues of the agri-food industry, amounts to approx. 1.7 billion m^3 of biogas per year (Energy Regulatory Office, 2021). Available data indicate (Institute of Renewable Energy, 2021) that annually, approx. 14 billion m^3 of natural gas is consumed in Poland, including approx. 500 million m^3 of gas is consumed by individual consumers in rural areas. The estimated amount of biogas after purification could cover about 10% of the domestic gas demand or fully meet the needs of rural customers and provide an additional 125 thousand MWhe (electricity) and 200 000 MWhc (heat).

The essence of the potential of the biogas market was recognised by the Polish authorities in the document "Directions for the development of agricultural biogas plants in Poland in the years 2010-2020". This document highlights the importance of optimal conditions for the development of agricultural biogas installations to be used for electricity and heat production (Ministry of Economy, 2009). It is worth noting that, under Directive 2009/28/EC, Member States are required to ensure a certain share of energy from renewable sources in the final gross consumption of energy (Directive,

DOI: 10.34659/eis.2022.83.4.492

2009). Therefore, the issue of agricultural biogas becomes as topical as possible and worthy of a broader discussion in connection with the unfavourable legislative changes concerning photovoltaic or wind installations and the current high energy and heat prices (Lipiński et al., 2018; Augustyn & Mirowski, 2018).

In the extensive literature of the subject, descriptions regarding the possibility of achieving ecological effects related to the use of biogas can be found (Mamica et al., 2022; Korys et al., 2019; Kozłowski et al., 2019). However, the analysis of the available literature has shown that it is limited to considerations concerning agricultural biogas and individual case studies. In particular, there is a lack of publications in relation to the energy and economic impact assessment. Therefore, the presented study is an attempt to fill the gap in the literature by discussing the essence of the potential of the agricultural biogas market in Poland on the example of a selected case study of a biogas plant project, along with an estimation of the environmental effect of the project on agricultural biogas in a selected destination where the agricultural economy plays a dominant role.

In the presented form, this article has many important practical and theoretical implications in an interdisciplinary perspective. The considerations in the thesis were organised as follows. Chapter 2 contains a description of the research method used in response to the set purpose of the thesis. Chapter 3 presents the characteristics of the agricultural biogas production market in Poland in terms of individual voivodships and against the background of selected European Union countries. Chapter 4 presents the assessment of the ecological effect on the example of agricultural biogas. The thesis ends with conclusions in which current research limitations were indicated. Also, future directions of research in relation to the issues related to the assessment of both the potential of the biogas market in Poland and the economic and energy benefits related to its development were identified.

Materials and methods

Anaerobic digestion of biomass is a process that has been used for years. However, in the perspective of the current paradigm of sustainable development, it is gaining a new face, especially in the context of the carbon footprint issue. To outline the broader circumstances of the problem, the article is divided into two parts. In the first, the potential of the agricultural biogas market in Poland is characterised, and in the second, on the basis of an agricultural biogas plant project, it is shown that the provision of energy from a biogas plant makes it possible to reduce carbon dioxide emissions into the air. This is a significant environmental effect both locally and globally.

The article uses statistical data based on the reports of the Central Statistical Office and the report of the National Centre for Agricultural Support in Poland, thanks to which it was possible to assess the potential of the agricultural biogas market in Poland (Central Statistical Office, 2020; Central Statistical Office, 2021; Ministry of Economy, 2010). The research period covered the years 2016-2020, and due to the availability of data in some cases, it was extended until 2021. In the following part, the considerations in the article are also a case study. They focus on assessing the ecological effect on the example of the Marcinkowice agricultural biogas plant (Development study, 2019). The choice of this destination was not accidental but was dictated by the desire to evaluate the actual project. Detailed calculations of carbon dioxide emission savings resulting from the implementation of the project in renewable energy sources, i.e. an agricultural biogas plant, were made based on the methodology for calculating the carbon dioxide emission reduction coefficient for the Operational Programme Infrastructure and Environment 2014-2020 (sub-measure 1.6.1 POI & Ś). The research results are presented in tabular, graphic and descriptive form in individual chapters of the work. The effect represents the result of implementing projects in the field of atmospheric protection and prevention of climate change, and it determines the amount of reduced CO_2 emissions.

Reduced carbon dioxide (CO_2) emissions should be understood as the reduction in emissions achieved as a result of the implementation of projects that reduce or eliminate entirely the consumption of energy chemical energy contained in fossil fuels. In order to calculate the size of the effect (reduction or avoidance of carbon dioxide (CO_2) emissions), emissions should be calculated (before and after the implementation of the project) using the carbon dioxide (CO_2) emission factors (in kg/GJ) recommended for use for a given year by the National Centre for Balancing and Emission Management.

Biogas production in Poland

Biogas production in individual voivodeships

As indicated in the literature on the subject (Tomaszewski, 2020), frequent changes in the law, oligopolies of raw material suppliers, and difficulties in obtaining financing are factors inhibiting the development of biogas plants in Poland. Their total number by 2025 is estimated at 1500-2100 units. According to the available data, at the end of 2020 in Poland, there were 316 biogas plants, 116 of which were agricultural biogas plants, 100 were biogas plants located near wastewater treatment plants, and another 100 were biogas plants at landfills (Biogas Barometer, 2020; Institute of Renewable Energy, 2021).

DOI: 10.34659/eis.2022.83.4.492

Figure 1 shows the production of agricultural biogas in Poland in 2012-2020. Geographical analyses indicate that most agricultural biogas plants are located in the following voivodeships: Zachodniopomorskie, Wielkopolskie and Warmińsko-Mazurskie. These regions have the best conditions for growing energy crops (including the area they can devote to them), the most developed agri-food industry, and their farmers raise the largest number of animals (per farm). The last two factors are particularly important because they indicate the access to large quantities of free raw material for the production of biogas, i.e. manure and animal excrement, e.g. in the form of slurry. The smallest number of agricultural biogas plants operate in the Opole, Świętokrzyskie and Śląskie voivodeships (Report, 2021).

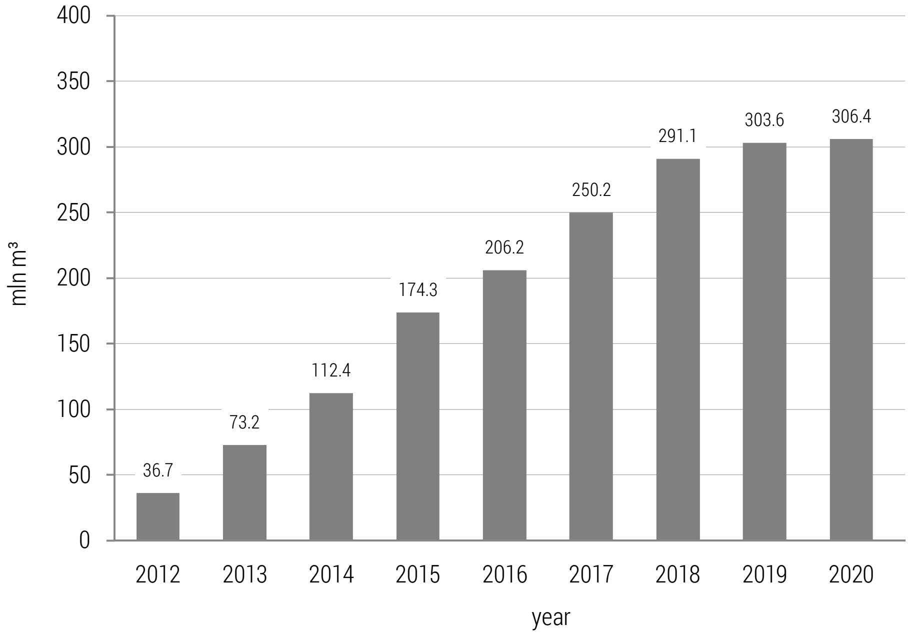

Figure 1. Production of agricultural biogas in Poland in 2012-2020 [in million m³]
Source: authors' work based on the Report (2021).

According to the reports (National Center for Agricultural Support, 2021) for 2020, over 3.96 million tonnes of raw materials were used to produce agricultural biogas, including decoction of the distillery (20.7% of the total raw materials used), followed by fruit and plant residues (19.5%), slurry (18.5%), maize silage (10.6%) and beetroot pulp (6.3%). Waste accounted for approx. 88% of raw materials are used for the production of agricultural biogas, and 12% – are cereals intended for purposes. The growth of biogas

DOI: 10.34659/eis.2022.83.4.492

production was mainly influenced by the well-developed food sector and agriculture, which ensured a constant supply of raw materials for biogas plants. The extraction of biogas from landfills in the years 2016-2020 is shown in Figure 2.

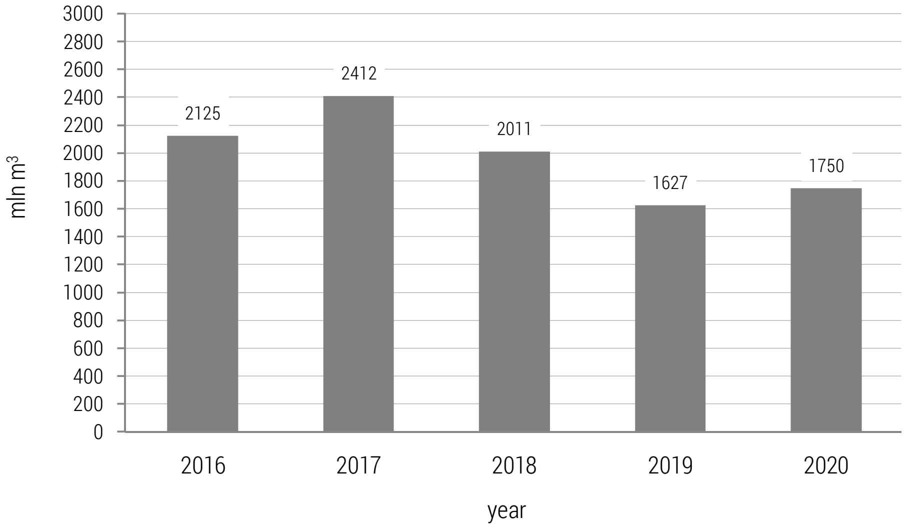

Figure 2. Obtaining biogas from landfills in 2016-2020 [in TJ]
Source: authors' work based on Central Statistical Office (2021).

As biogas plants producing energy from biogas from sewage treatment plants, they constituted 35% and were the dominant type of biogas plant (106 installations). In terms of the number of installations, the second place was occupied by power plants producing energy from biogas from landfills (33% – 100 biogas plants) (Central Statistical Office, 2021). The data contained in the above figure show that in 2016-2020, biogas extraction from landfills varied. Since 2017, a downward trend has been observed, followed in most cases by an increase in production in 2020 (Kwaśniewski et al., 2022).

The available data indicate that biogas plants producing energy from mixed biogas constituted 1% of all biogas plants and occurred individually in four voivodeships – Śląskie, Zachodniopomorskie, Lubelskie and Dolnośląskie. However, the dominant type of agricultural biogas plants are those that generate energy from biogas from sewage treatment plants. The data in this respect is shown in Figure 3.

The data analysis in Figure 3 shows that the production of biogas from sewage treatment plants in Poland in 2016-2020 was diverse. Biogas production increased in 2017, then decreased in 2018, and since 2019 there has been another increase.

DOI: 10.34659/eis.2022.83.4.492

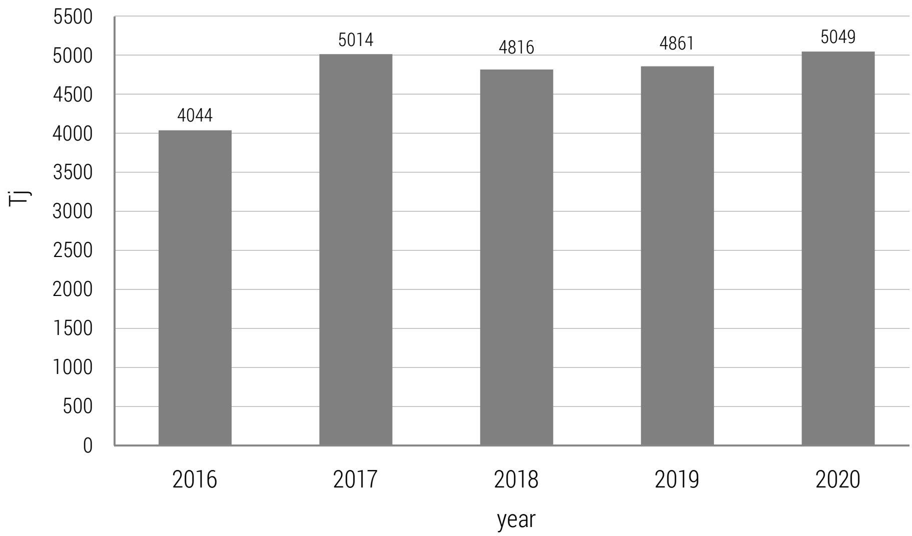

Figure 3. Obtaining biogas from sewage treatment plants in Poland in 2016-2020 [in TJ]
Source: authors' work based on Central Statistical Office (2021).

It should be emphasised that, for example, in the Silesian Voivodeship, biogas plants powered by raw material from sewage treatment plants had a large share. In turn, the smallest biogas plants operated in the Świętokrzyskie, Opolskie and Lubuskie voivodships, and their capacity was one of the smallest in the country (max. 4.3 MW in Lubuskie). The dominant type of biogas power plants in these voivodeships were installations using biogas from sewage treatment plants (Central Statistical Office, 2021).

To sum up, after analysing the share of individual types of biogas plants in Poland, it is possible to distinguish the regions in which the selected type of biogas plants was dominant. Agricultural biogas plants dominated in voivodeships in the western part of Poland (Lubuskie) through the northern part (West Pomeranian, Pomeranian and Warmian-Masurian) and in the eastern part (Podlaskie and Lubelskie).

The analysis of the available data indicates that the central part of Poland was dominated by power plants producing energy from landfill biogas. In turn, power plants producing energy from biogas from sewage treatment plants were located in the southern part of Poland (Opolskie, Śląskie, Małopolskie and Podkarpackie Voivodeships). Pomeranian Voivodeship stands out in terms of installation efficiency – 19 biogas plants were created there. 22.1 MW of energy (mainly agricultural biogas plants), while in the Silesian Voivodeship, almost twice as many installations (35) generated approx. 22.1 MW of energy. 21.4 MW. Most biogas plants in the Silesian Voivodeship

DOI: 10.34659/eis.2022.83.4.492

generate energy from biogas from sewage treatment plants (Central Statistical Office, 2021).

The available data show that at the end of 2020 in Poland, the installed electricity capacity of 116 biogas plants reached 126.912 MW. All energy producers included in the central register of economic activities defined economic activity as concentrated exclusively in the production of electricity from agricultural biogas.

Biogas production in Poland against the background of selected European Union countries

According to the available reports and studies, biogas and biomethane are important elements of the energy system in countries with a well-developed agricultural sector (EBA, 2018; Alatzas et al., 2019; Niemczyk et al., 2022). The aim of the biogas industry is to manage those raw materials which are considered waste. However, the dynamic increase in the share of this industry depends mainly on the existence of sufficiently strong administrative and government support mechanisms.

The available data indicate that Germany is the largest European market for biogas, both in terms of the number of production units and the amount of fuel produced (European Commission, 2021). This raw material accounts for 14% of electricity production from renewable sources. Centres for the production and use of this fuel are relatively evenly distributed across all the Länder, although the highest concentration is found in the north of Germany.

The biogas sector also plays an important role in the German labour market. This industry offers employment of approx. 345 thousand employees (as of 2017). Legislation introducing favourable support schemes, including the EEG-Act (Erneuerbare-Energien-Gesetz), which entered into force in 2000, introducing, i.a. feed-in tariffs. Since 2017, the solutions offered by this document also include longer financing perspectives for existing units (until 2030), a package supporting the development of biogas-based energy and provisions making the existing regulations more flexible. As a result, at the end of 2019, 9527 biogas plants operated in Germany (EBA, 2018).

The biogas sector in Italy developed dynamically in 2008-2012, thanks to the feed-in tariff system (Murano et al., 2021). At that time, they were the highest in the European Union in terms of support offered to small biogas plants using slurry and energy crops. In just two years (2010-2012), the number of biogas plants in Italy has risen from 510 to 1264, and electricity generation from this raw material has risen from 1.6 to 7.4 TWh in five years (2008-2013). However, after a period of rapid growth, the Italian government has reduced its support for the sector to the development of small biogas plants (up to 600 kW). At that time, work began on installations for the

DOI: 10.34659/eis.2022.83.4.492

production of biomethane. However, these were not very effective, and at the end of 2017, there were only 8 such units in Italy. In 2018, the Italian government adopted the so-called Biomethane Decree – regulations that were to lead to faster development of the biomethane sector (EBA, 2018).

By comparison, the UK is one of three countries in Europe), alongside Sweden and Estonia, where sewage is the most important substrate for biogas production. In other cases, it is produced mainly from energy plants and agricultural and municipal waste. The cost-effectiveness of biogas production in the United Kingdom is based primarily on a properly constructed model for the certification of renewable energy sources. The first commercial installation for the production of this fuel was built in Great Britain in 1982. Currently, there are biogas production units in the British Isles with a total installed capacity of approximately 630 MW (Jinqi et al., 2022).

According to the statistical report of the European Biogas Society (EBA, 2018), a total of 18,202 biogas plants were operating in Europe in 2018, and the installed capacity across Europe amounted to 1,1082 MW. The largest number of biogas plants was in Germany (over 11 thousand installations), Poland with 304 installations ranked 8th. An interesting case was the Czech Republic, which at that time had 574 biogas plants, but per 1 million inhabitants (54 units), were in third place after Germany (138 units) and Switzerland (77 units). Poland had only 8 biogas plants per 1 million inhabitants, and in this ranking, it occupied 24th place in 2018.

Figure 4 shows the share of biogas energy in the acquisition of energy from renewable sources in 2018 and 2021 in Poland and selected for data availability in European Union countries.

The data presented in Figure 4 show that the share of biogas energy in the acquisition of energy from renewable sources in 2018 and 2021 in Poland and the European Union was very diverse. This state of affairs was influenced by many factors, including legal and administrative regulations.

In 2021, only Poland (0.6%), the Netherlands (0.2%), and Finland (0.6%) recorded an increase in the acquisition of energy from biogas compared to 2018. In the remaining countries, there was a decrease, the largest in Germany (1.2%). The largest share of biogas energy in the acquisition from renewable sources in 201-2018 was recorded in Germany and the Czech Republic. The smallest – are in Finland, Austria and Poland. The average European share of biogas in the production of energy from renewable sources was over 7%. Italy, Slovakia and Lithuania have a similar share to the European average (Eyl-Mazzegaand & Mathieu, 2019).

DOI: 10.34659/eis.2022.83.4.492

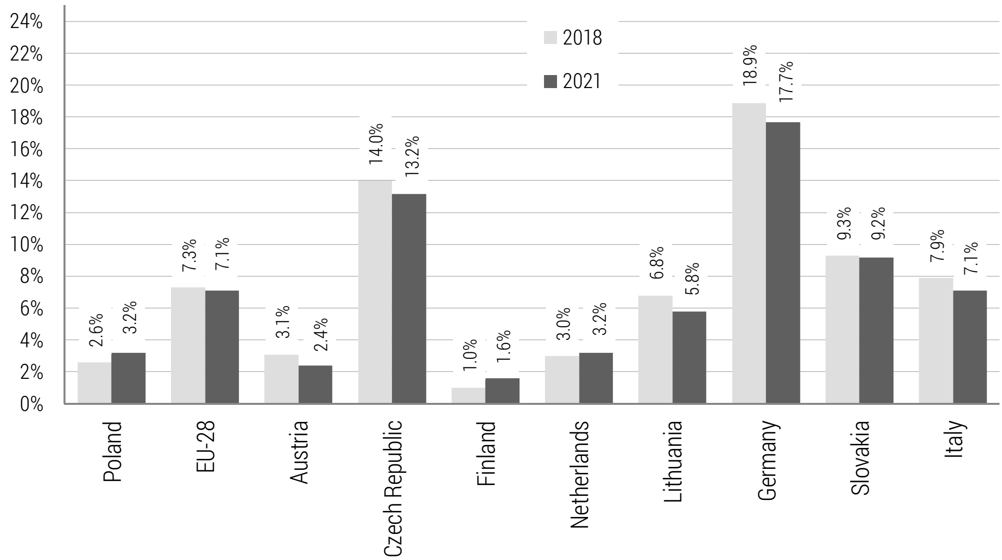

Figure 4. The share of biogas energy in the acquisition of energy from renewable sources in 2018 and 2021

Source: authors' work based on Central Statistical Office (2021).

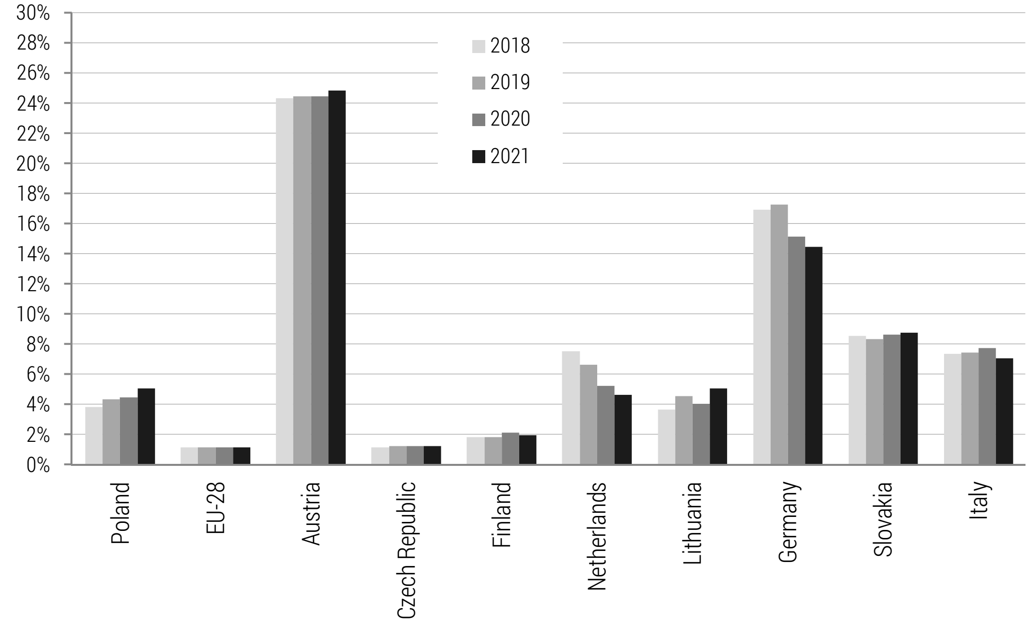

Figure 5. The share of biogas energy in the production of electricity from renewable sources in Poland and selected EU-28 countries in 2018 and 2021

Source: authors' work based on Central Statistical Office (2021).

DOI: 10.34659/eis.2022.83.4.492

The potential of the biogas sector and the EU regulatory environment indicate that, in the opinion of the authors, the biogas sector may play an important role in the Polish energy mix. Meanwhile, currently, it is not sufficiently appreciated and used. Such a small use of biogas technology in the Polish energy system results, to a large extent, from the existence of regulatory and legal barriers, which either hinder the use of some of the available technological solutions or reduce the economic attractiveness of investments in the development of biogas installations (Pietrzak et al., 2021).

The share of energy from biogas in the production of electricity from renewable sources in Poland and selected EU-28 countries is shown in Figure 5.

The share of electricity obtained from biogas in 2018 and 2021 varied significantly across the EU. In Poland, Lithuania and the Czech Republic, there was a noticeable increase by 1.2, 1.5 and 0.5%. In the Netherlands and Germany, however, its share decreased by 2.9% and 2.5%, respectively. The largest share of energy from biogas in the production of electricity from renewable sources was recorded in Austria and then in Germany. Since 2006, the biogas market in Austria has been fully liberalised. In conclusion, the introduction of regulations limiting the use of food-type energy plants for the production of biogas has reduced the attractiveness of the conditions of payment for electricity from biogas. Nevertheless, some Member States have seen a positive increase in production due to their determination to promote both the production of biomethane and the recovery of energy from fermentation waste (ACT of 8 January, 2010).

Assessment of the ecological effect on the example of the Marcinkowice agricultural biogas plant

One example of renewable energy solutions is the planned Marcinkowice agricultural biogas plant. (Development study of the investment, 2019). The aim of the Marcinkowice investment is to generate electricity and heat from biogas obtained in the process of anaerobic fermentation of raw materials (corn silage) carried out using specialised strains of bacteria. It should be emphasised that Marcinkowice is an agricultural township with conditions conducive to the development of installations for the production of energy from renewable sources. There is currently one agricultural biogas plant, the capacity of which is fully used for the heat supply of the existing food production plant (confectionery production). Analysis of the needs of the local community indicates that the inhabitants are struggling with the growing demand for electricity. Therefore, it is necessary to expand the existing energy infrastructure with an additional element – a biogas plant.

DOI: 10.34659/eis.2022.83.4.492

The project described here concerns the construction of an agricultural biogas plant with an electrical capacity of 1.1 MWe and thermal power of 1.04 MWt, together with the accompanying technical infrastructure.

The basic substrate in the planned installation, which constitutes energy fuel, is potato pulp, vegetable substrates (corn silage and other green biomass) and animal manure. The use of other products, such as post-boiler stock and bakery waste, is also allowed. Biogas production will occur using anaerobic methane fermentation.

The project assumes that substrate requirements will be: potato mash – 18,000 Mg/year, corn silage or other biomass – up to 8,000 Mg/year, manure – up to 4,000 Mg/year.

Biogas production will take place using anaerobic methane fermentation. In the technological process of the biogas plant in operation, energy recovery will be carried out from food waste and agricultural production or waste agrarian production. Accordingly, thermal energy and co-generated electricity will be generated. In the process of biogas production, post-fermentation will be created, which according to the law, can be treated as waste with the possibility of use in the process of fertilising agricultural fields. The digested product is separated into a liquid and solid phase. The liquid phase will be used to dilute plant matter, while the excess will be used to improve the quality of soils in agricultural areas. The plant in question uses a closed liquid circuit, which definitely minimises the need for water and the generation of liquid process wastewater. The planned installation will produce biogas, which will be used as fuel for power generation in cogeneration. This gas will power the cogeneration unit, and the electricity and heat produced will primarily cover the biogas plant's own needs, with surpluses being given away: heat to the supplier of the basic raw material company "Nowamyl", electricity to the local transmission grid.

The research aimed to determine the ecological effect of energy production in the Marcinkowice agricultural biogas plant by calculating the "emission reduction factor carbon dioxide CO_2." (Ministry of Economic Development, 2014). For this purpose, detailed calculations of carbon savings resulting from the implementation of the project in renewable energies sources were carried out based on the methodology of calculating the carbon dioxide emission reduction factor for the Operational Programme Infrastructure and Environment 2014-2020 (sub-measure 1.6.1 OPI and E). Table 1 presents the base data resulting from the project assumptions.

DOI: 10.34659/eis.2022.83.4.492

Table 1. Quantitative parameters for the implementation of the Marcinkowice biogas plant project

Description	Measurement units	Value
Biogas plant electrical power	MW	0.499
Thermal power of biogas plant	MW	0.54
Biogas plant operating time	H	8400
Gross amount of electricity produced (product of Biogas plant electrical power and Biogas plant operating time)	MWh	4192
Share of electricity for own needs	%	10.0
Including the amount of energy su%lied to the power system	MWh	3772.44
Conversion factor MWh to GJ	-	3.6
Amount of useful heat that can be generated (product of Biogas plant electrical power, Biogas plant operating time and Conversion factor MWh to GJ)	GJ	16329.6
Share of electricity consumed for own needs	%	15.0
Amount of heat consumed for own needs (Amount of useful heat that can be generated and Share of electricity consumed for own needs)	GJ	2449.44
Number of days per year on which the recipient can use the heat	Days	365
Amount of external heat that can be used by the recipient	GJ	13880.16
Reference efficiency for separate production of electricity (for biogas)	%	40
Reference efficiency for separate production of heat (biogas)	%	43
Limit efficiency (for a reciprocating internal combustion engine, points 1.2 and 1.3, Annex No. 1 to the Regulation Journal of Laws of 2017, item 834)	%	75
Correction multiplier for electricity other than own needs, e.g. introduced into the network (assumption: for voltage ≥ 12 – < 50 kV)	-	0.935
Correction multiplier for electricity consumed for own needs (assumption: for voltage from >=0.45kV to <12kV)	-	0.891
Calorific value of methane	MJ m^{-3}	35.73
Average CH4 (methane) share in biogas	%	60
Amount of biogas consumed	m^3	2 092 650

Source: authors' work based on data from the Development study Marcinkowice.

The calculations showed that the nominal heat output of the cogeneration source (the energy introduced in the fuel at the nominal load of the source) will be 1248 MW, including:

- electrical power of the biogas plant – 0.499 MWe,

- electrical power of the cogeneration source (lower consumption for own needs of the installation) 0.4491 MWe,
- heat output of the biogas plant – 0.540 MWt,
- heat output of the cogeneration source (lower consumption for the own needs of the installation) 0.459 MWt.

The electricity produced as a part of the investment is to be supplied to the local operator's power grid and the heat to an industrial customer (fish farming) located in the immediate vicinity of the investment. According to the calculations, the amount of energy transferred to the power system will be 3772.44 MWh, and the amount of useful heat that can be generated will be 16 329.6 GJ.

Table 2. Calculation of the direct result indicator 'Emission reduction CO_2'

Description	Measurement units	Value
Annual carbon dioxide emissions replaced (avoided) due to the project implementation		
CO_2 emission factor for electricity generation only, including transmission losses (former customer) – typical power plant supplying the National Power System (National Center for Balancing and Emission Management, 2020).	kg/GJ	267.6
CO_2 emission factor for heat production only (ex-producer) – typical coal-fired power plant (National Center for Balancing and Emission Management, 2020).	kg/GJ	126.5
Other assumptions: 1. The calculation does not include carbon dioxide emissions for energy produced for own needs. 2. Heat receiver – reports heat demand throughout the year. This is due to the fact that this heat is needed for production processes. Therefore, the calculations were made for the whole year, without division into the heating season and the period outside the heating season.		
CO_2 reduction – Electricity (Ete)	Mg	3 634.2
CO_2 reduction – thermal energy (etc.)	Mg	1 755.8
Total avoided CO_2 emissions (E1)	Mg	5 390.1
Annual emissions of carbon dioxide from the installation after project implementation		
Annual emissions of carbon dioxide from the installation after the implementation of the project (only biogas dispersed for energy production will be used, for which the emission factor, in accordance with Table 2 of the adopted methodology [3], is 0kg/GJ	Mg	0.00
Value of the CO_2 reduction indicator		
Value of the CO_2 reduction indicator	Mg	5 390.1

Source: authors' work based on data from Development study Marcinkowice.

DOI: 10.34659/eis.2022.83.4.492

The operation of the constructed installation will avoid the emission of CO_2 as a result of not connecting the energy consumers from the installation to the National Power Network and the Local Heating Network. The avoided carbon dioxide emissions related to the generated EEE electricity, in accordance with the adopted method, will amount to 3.634.2 Mg, while the avoided carbon dioxide emissions related to the limitation of heat generation Etc will amount to 1.755.8 Mg.

In order to calculate the carbon savings resulting from the implementation of the project, the following formula was used:

$$\Delta E = E1 - E2 \text{ [t/year]}, \quad (1)$$

where:

E1 – annual carbon dioxide emissions replaced (avoided) as a result of the project implementation [t/year],

E2 – annual emissions of carbon dioxide from the installation after project implementation [t/year].

For all renewable energy installations, the value of the carbon dioxide emission factors in relation to the generated energy is assumed to be zero, i.e. the carbon dioxide emission from these installations does not occur E2 = 0 [t/year]. The estimated annual reduction in greenhouse gas (CI) emissions is 5390.10 tonnes of CO_2 equivalent (Dictionary of environmental protection, 2022).

In conclusion, the presented simulations in the scope of all manufactured products (electricity, heat) constitute a key argument for promoting the development of this type of investment, which is a biogas plant. The functioning of the biogas plant will reduce the emission of harmful chemical compounds (including greenhouse gases) resulting from conventional processes of electricity and heat generation. Writing into the objectives and directions of development related to the sustainable management of environmental resources and the development of renewable energy sources in Poland.

Conclusions and summary

Undoubtedly, renewable energy sources will play an increasing role in global energy production (Ministry of Economy, 2009; European Commission, 2021). This process will be compounded by the deteriorating state of the natural environment and the growing energy intensity of many branches of modern industry (Sikora et al., 2020; Somers et al., 2018; Cesaro,2020). Higher energy consumption will also be driven by an increase in the world's population. However, the structure of energy consumption in Poland differs

DOI: 10.34659/eis.2022.83.4.492

from that in highly developed EU countries, mainly due to the dominant share of coal and the lack of nuclear energy. It is in recent years that changes aimed at diversification of the Polish energy sector have been noticed (Pietrzak et al., 2021).

The presented considerations in this article confirmed the increased interest in the production of biogas by domestic farms. In the period under review, the amount of biogas produced in Poland increased steadily. Many factors influenced this situation, including the well-developed food sector and agriculture, which ensured a constant supply of raw materials for biogas plants. In addition, the expected changes in legal regulations have contributed to the growth in the development of biogas plants. However, it should be mentioned that this increase is inadequate for Poland's potential (Mamica et al., 2022). The dominant type of biogas plants in the country in 2017-2021 were installations using biogas from sewage treatment plants and landfills. On the other hand, the number of renewable energy source installations using biogas in individual voivodships still varies. Agricultural biogas plants dominate in Lubuskie, Zachodniopomorskie, Pomorskie and Warmińsko-Mazurskie, Podlaskie and Lubelskie voivodships. In turn, power plants producing energy from biogas from sewage treatment plants are located in the following voivodships: Opolskie, Śląskie, Małopolskie and Podkarpackie. In the central part of Poland, most power plants produce energy from landfill biogas.

The presented case study shows that the building of an agricultural biogas plant reduces greenhouse gas emissions by reducing carbon dioxide emissions to the atmosphere. Furthermore, the production of agricultural biogas can contribute to improving the energy security of the region by increasing the energy supply using domestic raw materials. Thus, the fermentation of agricultural biomass, leading to the formation of biogas, may lead to achieving ecological and economic benefits, especially when we take into account the possibility of using large raw materials resources found in Polish agriculture. On this basis, the authors postulate that the production of agricultural biogas should be perceived as one of the most promising directions of energy use of biomass and the development of renewable energy sources in Poland. Especially in areas where agriculture is dominant.

Production of agricultural biogas in renewable energy source installations contributes to the achievement of objectives in the aspect:

- environmental: reduction of carbon dioxide emissions, reduction of exploitation and combustion of fossil non-renewable energy sources, prevention of environmental degradation, fulfilment of Poland's accession commitments to increase the share of energy from renewable sources,

DOI: 10.34659/eis.2022.83.4.492

- social: improving the quality of life by reducing the inconvenience associated with greenhouse gas emissions, increasing the environmental awareness of residents,
- economic: use of local energy resources, support of socio-economic development (construction of biogas plant gives the opportunity to create new jobs), an increase of investment attractiveness of the region (opening to new technologies), energy independence.

Summing up the presented research on the essence of the potential of the agricultural biogas market in Poland – the case study of the biogas project does not fully exhaust the essence of the issue. They are only an incentive for further research in this matter. Therefore, such analyses will be the subject of future work to define and identify the key factors for the implementation of an ambitious plan to develop renewable energy sources by increasing the importance of agricultural biogas in areas where the agricultural economy plays a dominant role.

The contribution of the authors

Agnieszka Brelik – conception, literature review, acquisition of data, analysis and interpretation of data – 25 %.

Wojciech Lewicki – conception, literature review, acquisition of data, analysis and interpretation of data – 25 %.

Milena Bera – conception, literature review, data acquisition, analysis and interpretation of data – 25%.

Monika Śpiewak-Szyjka – conception, literature review, acquisition of data, analysis and interpretation of data – 25%.

References

ACT of 20 February 2015 on renewable energy sources. Journal of Laws of 2015, item 478.

ACT of 8 January 2010 amending the Act – Energy Law and amending certain other acts. Journal of Laws of 2010, No.21, item 104.

Alatzas, S., Moustakas, K., Malamis, D., & Vakalis, S. (2019). Biomass potential from agricultural waste for energetic utilization in Greece. Energies, 12(6), 1095. https://doi.org/10.3390/en12061095

Augustyn, A., Mirowski, T. (2018). The possibilities of energy storage development in Poland from a long-term perspective. Politics and Society, 1(16). https://doi: 10.15584/polispol.2018.1.7

Bielski, S., Marx-Bielska, R., Zielińska-Chmielewska, A., Romaneckas, K., & Šarauskis, E. (2021). Importance of Agriculture in Creating Energy Security. A Case Study of Poland. Energies, 14(2465). https://doi.org/10.3390/en14092465

Biogas Barometr. EurObserv'ER. (2020, December). https://www.eurobserv-er.org/biogas-barometer-2020/

Central Statistical Office. (2020, June 28). www.stat.gov.pl

Central Statistical Office. (2021). Central Statistical Office. *Statistical analysis: Energy from renewable sources*.

Cesaro, A. (2020). The valorization of the anaerobic digestate from the organic fractions of municipal solid waste: Challenges and perspectives. Journal of Environmental Management, 280, 111742. https://doi.org/10.1016/j.jenvman.2020.111742

Czerwiakowska-Bojko, E., & Żmuda, K. (2009). Agricultural energy potential: agricultural biogas plants as the future of the Polish countryside. Clean Energy, 9(95).

Development study of the investment (2019). *Construction of a 1.2 MW installation for the production of electricity and heat from biogas*.

Dictionary of environmental protection. (2022). Now environment.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 to establish new energy sources from payment sources and repealing 2001/77/EC and 2003/30/EC. http://data.europa.eu/eli/dir/2009/28/2021-07-01

Drożdż, W., Mróz-Malik, O., & Kopiczko, M. (2021). The Future of the Polish Energy Mix in the Context of Social Expectations. Energies, 14(5341), 1-23. https://doi.org/10.3390/en14175341

EBA. (2018). European Biogas Association. *Statistical Report of the European Biogas Association*.

Energy Regulatory Office. (2021). The average price of Electricity for households.

European Commission. (2021). Emissions Cap and Allowances.

Eyl-Mazzegaand, M. A., & Mathieu, C. (2019). Biogas and Biomethane in Europe: Lessons from Denmark, Germany and Italy. Études de l'Ifri. Ifri, 8,36. https://www.ifri.org/sites/default/files/atoms/files/mathieu_eyl-mazzega_biomethane_2019.pdf

Institute of Renewable Energy. (2021). Biogas Production Utilization.

Janiszewska, D. A., (2019). Diversification of energy production and consumption in European Union countries. Energy Policy Journal, 22(2), 5-20. https://doi.org/10.33223/epj/109338

Jinqi, L., Jihong, W., & Cardinal, J. (2022). Evolution and reform of UK electricity market. Renewable and Sustainable Energy. Elsevier, 161. https://doi.org/10.1016/j.rser.2022.112317

Korys, K. A., Latawiec, A. E., Grotkiewicz, K., & Kubon, M. (2019). The Review of Biomass Potential for Agricultural Biogas Production in Poland. Sustainability, 11(6515), 1-13. https://doi.org/10.3390/su11226515

Kozłowski, K., Pietrzykowski, M., Czekała, W., Dach, J., Kowalczyk-Juśko, A., Jóźwiakowski, K., & Brzoski, M. (2019). Energetic and economic analysis of biogas plant with using the dairy industry waste. Energy, 183, 1023-1031. https://doi.org/10.1016/j.energy.2019.06.179

Kwaśniewski, D., Płonka, A., & Mickiewicz, P. (2022). Harvesting Technologies and Costs of Biomass Production from Energy Crops Cultivated on Farms in the Małopolska Region. Energies, 15(1), 131. https://doi.org/10.3390/en15010131

Lipiński,. A. J., Lipiński S., & Kowalkowski, P. (2018). Utilization of post-production waste from fruit processing for energetic purposes: analysis of Polish potential and case study. Journal of Material Cyclesand Waste Management, 20(3), 1878-1883. https://doi.org/10.1007/s10163-018-0729-2

Mamica, Ł., Mazur-Bubak, M., & Wróbel-Rotter, R., (2022). Can Biogas Plants Become a Significant Part of the New Polish Energy Deal? Business Opportunities for Poland's Biogas Industry. Sustainability, 14(3), 1614.

Ministry of Economic Development. (2014). Operational Programme Infrastructure and Environment 2014-2020. Methodology for calculating the carbon dioxide emission reduction factor in sub-measure 1.6.1 Sources of high-efficiency cogeneration.

Ministry of Economy. (2009). Energy Policy of Poland until 2030. Appendix to Resolution no. 202/2009 of the Council of Ministers of 10 November 2009. https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/laws/1564%20English.pdf

Ministry of Economy. (2010). Direction of development of agricultural biogas plants in Poland in 2010-2020.

Ministry of Economy. (2010). National Action Plan for Renewable Energy Sources.

Murano, R., Maisano, N., Selvaggi, R., Pappalardo, G., & Pecorino, B. (2021). Critical Issues and Opportunities for Producing Biomethane in Italy. Energies, 14(9), 2431. https://doi.org/10.3390/en14092431

National Center for Balancing and Emission Management. (2020). Emission factors for CO_2, SO_2, NOx, CO and total dust for electricity based on information contained in the National Database on Emissions of greenhouse gases and other substances for 2019.

Niemczyk, J., Sus, A., Bielińska-Dusza, E., Trzaska, R., & Organa, M. (2022). Strategies of European Energy Producers: Directions of Evolution. Energies, 15(2), 609. https://doi.org/10.3390/en15020609

Pietrzak, M. B., Igliński, B., Kujawski, W., & Iwański, P. (2021). Energy Transition in Poland. Assessment of the Renewable Energy Sector. Energies, 14(2046), 1-23. https://doi.org/10.3390/en14082046

Report on the activities of the National Center for Agricultural Support in 2021. (2021). https://www.kowr.gov.pl/uploads/pliki/analizy/sprawozdania/SPRAWOZDANIE_KOWR_2021.pdf

Sikora, J., Niemiec, M., Szeląg-Sikora, A., Gródek-Szostak, Z., Kuboń, M., & Komorowska, M. (2020). The Effect of the Addition of a Fat Emulsifier on the Amount and Quality of the Obtained Biogas. Energies, 13(7), 1825. https://doi.org/10.3390/en13071825