www.jard.edu.pl http://dx.doi.org/10.17306/J.JARD.2017.00275

Journal of Agribusiness and Rural Development

pISSN 1899-5241
eISSN 1899-5772
1(43) 2017, 227–237

PROSPECTS FOR THE DEVELOPMENT OF THE AGRICULTURAL BIOGAS SECTOR IN POLAND

Magdalena Zubrzycka[1], Janusz Wojdalski[1✉], Karol Tucki[1], Mariusz Zubrzycki[2]

[1]Szkoła Główna Gospodarstwa Wiejskiego w Warszawie
[2]Politechnika Warszawska

Abstract. This article presents the legal regulations relating to Renewable Energy Sources, including the biogas sector. It discusses biogas production technologies, the current state and perspectives of agricultural biogas production in Poland, the production capabilities of Polish biogas plants and factors contributing to the attractiveness of the biogas sector. The following economic and ecological aspects of biogas production were considered in the study: profitability and environmental impacts, including reduction in carbon dioxide emissions. Despite numerous problems, the Renewable Energy Sources Act provides an opportunity for the growth and development of the biogas industry in Poland.

Keywords: biogas, renewable energy sources, attractiveness of the biogas sector, biomass

INTRODUCTION

The Polish agricultural biogas sector shows high promise due to the availability of substrates for biogas production and the European Union's sustainable energy strategy. Despite the above, investors have been postponing the launch of new biogas plants or reducing the output of the existing plants in Poland, mainly due to the low and variable prices of renewable energy certificates, which render biogas production unprofitable. Poland does not have a long-term development strategy for the power sector, and renewable energy projects require state funding. Source materials and publications addressing the renewable energy sector are developed by various institutes and centers, and they need to be systematized. This paper reviews the existing literature and attempts to synthesize information relating to biogas production, the prospects of the Polish biogas sector, and the economic and environmental aspects of biogas production.

LEGAL REGULATIONS AND THE ROLE OF ENVIRONMENTAL PROTECTION AGENCIES

The main goals of Poland's Energy Policy until 2030 is to improve Poland's energy and resource efficiency, guarantee safe access to fuel and energy, promote renewable sources of energy, promote the development of alternative fuel and energy markets, and minimize the environmental impacts of the energy sector. The targets set by the Energy Policy include 15% of final energy consumption from renewable sources by 2020, 10% of transport fuels from renewable sources by 2020, and the development of distributed energy resources. The document entitled "Development of agricultural biogas plants in Poland in 2010–2020" details the goals and expected outcomes of biogas production and lays down a support framework for the construction of 2,000 agricultural biogas plants. According to the National Action Plan (NAP), biogas contributes to the achievement of sustainable energy goals as a source of electricity and

✉prof. dr hab. inż. Janusz Wojdalski, Katedra Organizacji i Inżynierii Produkcji, Szkoła Główna Gospodarstwa Wiejskiego w Warszawie, ul. Nowoursynowska 166, 02-787 Warszawa, Poland, e-mail: janusz_wojdalski@sggw.pl

heat. In 2020, the amount of electricity generated from biogas is expected to increase by 125% in comparison with 2010. The amended Energy Law came into force on 11 September 2013 (Journal of Laws of 2012, item 1059, as amended) as part of the "Small Energy Three-Pack" which broadened the list of renewable energy sources to include aerothermal and hydrothermal energy from air and water, respectively. The amended Energy Law also introduced two types of energy generation systems:

- renewable energy microsystems with maximum installed capacity of 40 kW_{el} or 120 kW_t;
- small-scale renewable energy systems with installed capacity of 40 kW_{el}–200 kW_{el} or 120 kW_t–600 kW_t.

The amended Energy Law introduces financial incentives for connecting microsystems to the power grid by releasing the microsystem operator from connection fees. Microsystem operators are not required to start a business or obtain generation licenses. Energy generated by a microsystem is sold to the public grid for 80% of the average price of energy charged in the previous year. The Act on Renewable Energy Sources of 20 February 2015 sets forth the terms and conditions for the generation of energy from agricultural biogas. Biogas is a product of methane fermentation of agricultural products, agricultural by-products, liquid and solid manure, wastes, by-products and residues from the processing of biological materials, forest and plant biomass harvested from areas other than farm fields and forests, excluding biogas from treated effluents and landfills. As of 2014, owners of renewable energy microsystems can apply for subsidies from the National Fund for Environmental Protection and Water Economy as part of the Bocian (Stork) program. Projects aiming to reduce or eliminate CO_2 emissions and increase the production of green energy are prioritized. The Fund has also developed the Green Investments System which provides loans and subsidies to agricultural biogas plants. Plant operators can apply for subsidies to co-finance the cost of purchasing, producing, installing and commissioning fixed assets, purchasing construction materials and services, and purchasing intangible assets such as patents, licenses and technologies. As part of the measures aiming to diversify sources of non-farming income under the Rural Development Program for 2007–2013, operators can obtain up to PLN 500,000 in non-refundable grants for the construction of agricultural biogas plants. The amount of the grant cannot exceed 50% of qualified project costs. Under the Infrastructure and Environment Operational Program for 2014–2020, the support for low emission technologies for agricultural biogas plants ranges from 30% to 50% of qualified expenses, not more than PLN 40 million per project.

PRESENT STATUS AND LOCATION OF BIOGAS PLANTS IN POLAND

The goal of the "Biogas plant in every municipality" strategy was to build 2,000 agricultural biogas plants in Poland by 2020. The progress made so far indicates that this ambitious undertaking is unlikely to be completed by the set deadline. The location of biogas plants is presented in Figure 1.

According to the Agricultural Property Agency (ARR), there are 93 agricultural biogas plants operated by 83 companies in Poland. Of those, 10 plants have installed capacity of 2 MWe and more, 28 plants – 1 to 1.99 MWe, and the remaining facilities are small biogas plants with installed capacity of less than 1 MWe. The total output of Polish agricultural biogas plants (estimated methane content of 55–60%) is around 386 million m^3/year.

Small biogas plants fed with agricultural waste and by-products (animal manure, silage) had been developing rapidly in Germany until the year 2000. In the Czech Republic, public funding led to the rapid growth of the biogas sector in the last three years. The Czech government supports the green certificate system and has introduced a lump-sum fee for the purchase of energy generated from renewable sources (the fee is set by the government, and it is higher than the price of energy paid by consumers). Those measures were adopted by the Czech Republic to meet the target of 8% of final energy consumption from renewable sources by 2015. The offered support increases the profitability of environmentally-friendly projects on the energy market. The Polish biogas industry could benefit from the good practices implemented by Germany, Austria and the Czech Republic. In the past two decades, biogas production was expanded and the methods for its utilization have been improved in Germany. If Poland and Germany have similar potential for the production of agricultural biogas and German farms derive profits from biogas plants, such schemes should also generate benefits for Polish producers. In Poland, the terms on which grants are awarded to biogas producers are somewhat ambiguous. The price of energy generated in Poland is around

Fig. 1. Location of agricultural biogas plants in Poland
Source: own elaboration based on information from the Agricultural Property Agency, retrieved on 17 November 2016
Rys. 1. Rozmieszczenie biogazowni rolniczych w Polsce
Źródło: opracowanie własne na podstawie danych ARR na dzień 17.11.2016

PLN 0.37/kWh (€ 0.08/kWh) (price of energy with a certificate of origin). By comparison, German prices are more than 100% higher. In some Polish regions, there are problems with connecting biogas plants to outdated power grids. Despite the above, biogas production is still regarded as a promising method for biomass utilization. The Polish Act on Renewable Sources of Energy calls for the development of a list of suitable substrates for the generation of agricultural biogas and electricity. According to the Act, biogas includes landfill gas, the biodegradation product of the organic fraction of municipal waste, as well as gas from treated effluents, the product of methane fermentation of sediments formed during biological treatment of wastewater. The terms on which the energy generated by household microsystems with the output of up to 3 kW can be sold to the power grid should be set with greater precision. Microsystems rely on various substrates, and the generated energy is sold at a fixed price over a period of 15 years (for the first 300 MW only). Only the first 500 MW of energy generated by microsystems with the output of 3 to 10 kW is sold at a guaranteed price. The present strategy for the power sector supports the development of systems with low energy output. The Act on Renewable Energy Sources will introduce the formal definition of a microsystem (up to 40 kW) and a small-scale system (40–100 kW), which will lead to greater clarity in the process of formulating criteria for awarding grants and subsidies. In line with the distributed energy concept, biomass can be converted to energy in local micro-biogas plants. In Poland, micro-biogas plants with the output of 10–20 kW_{el} could be operated by 200,000 farms.

This implies that more than 90% of Polish farms can generate energy catering to the needs of agricultural operations and the local community. However, investors have a greater interest in systems with the minimum output of 1 MW.

SUBSTRATES FOR BIOGAS PRODUCTION

Substrates for biogas production differ in chemical composition. Biogas substrates used in 2012–2014 and biogas utilization are presented in Tables 1 and 2.

Table 1. Substrates used in the production of agricultural biogas in Poland in 2012–2014 (tons)
Tabela 1. Surowce wykorzystywane do produkcji biogazu rolniczego Polsce w latach 2012–2014 (tony)

Substrate Surowiec	Year – Rok		
	2012	2013	2014
Slurry Gnojowica	39.49%	30.39%	29.86%
Maize silage Kiszonka z kukurydzy	27.33%	19.18%	21.67%
Distillery wastes Wywar gorzelniczy	16.58%	23.67%	18.17%
Fruit and vegetable processing wastes Pozostałości z przetwórstwa warzyw i owoców	9.74%	17.92%	18.51%
Beet pulp Wysłodki buraczane	4.20%	6.78%	9.86%
Manure Obornik	2.66%	2.06%	1.93%
Total (tons) Łącznie (tony)	884 064.80	1 498 968.88	1922 333.37

Source: www.arr.gov.pl.
Źródło: www.arr.gov.pl.

Table 2. Production of agricultural biogas, electricity and heat from agricultural biogas in 2011–2015
Tabela 2. Produkcja biogazu rolniczego, energii elektrycznej i ciepła z biogazu rolniczego w latach 2011–2015

Year Rok	Agricultural biogas Ilość wytworzonego biogazu rolniczego [mln m^3]	Electricity generated from agricultural biogas Ilość energii elektrycznej wytworzonej z biogazu rolniczego [GWh]	Heat generated from agricultural biogas Ilość ciepła wytworzonego z biogazu rolniczego [GWh]
2011	36.646	73.433	82.638
2012	73.152	141.804	160.128
2013	112.412	227.890	246.557
2014	174.253	354.978	373.906
2015	206.579	429.400	224.996*

Source: www.arr.gov.pl.
Źródło: www.arr.gov.pl.

The most popular substrates for the production of electricity from agricultural biogas are slurry, maize silage, distillery wastes and by-products of fruit and vegetable processing. In 2014, those substrates accounted for approximately 86% of total organic materials processed in agricultural biogas plants. Fugol and Prask (2011) compared the biogas yield of three types of silages (maize, alfalfa, and grass).

The data in Table 2 indicates that in 2014, the production of agricultural gas increased by around 55% from 2013. In 2015, the relevant increase from 2014 was only 19%. The capacity of the existing biogas plants is not fully utilized. Szlachta and Fugol (2009) analyzed the profitability of biogas production in a cogeneration system where the substrate was a 30/70% and 70/30% mixture of slurry and maize silage. Proceeds from the sale of certificates can provide an additional source of income for biogas plants, but the production of biogas from substrate containing 70% maize silage, purchased at the cost of PLN 60 per ton and higher, generated a loss.

THE USE OF BIOMASS AND WASTE FOR BIOGAS GENERATION

The exact amount of energy that can be derived from biomass is difficult to determine in the long term due to changes in land use and technological progress in agriculture. According to the Institute for Renewable Energy (IRE), the economic potential of biogas in 2020 will reach 6.6 billion m^3, which corresponds to 204 PJ of energy. The Polish agricultural sector, the fruit and vegetable processing industry and animal farming produce vast amounts of wastes and byproducts which can be used as substrates for biogas production (Czyżyk et al., 2010). There are plans to plant 700,000 hectares with energy crops to cater to domestic demand for food and substrates for energy generation. The energy potential of wastes and byproducts from agriculture and food processing is estimated at 1.7 billion m^3 of biogas per year, which is equivalent to 847 ktoe and 35.6 PJ. The above amount would cover 1.2% of final energy consumption. The biomass potential of the European Union has been estimated in the REFUEL project. Poland can fulfill 12% (2200 PJ) of Europe's biomass energy capacity (17.5 EJ/year). Biomass is regarded as a complementary source of energy, and animal production could also serve as an alternative energy source. According to the Institute for Renewable Energy (IRE), large animal herds, such as 100 cows, 500 pigs or 5000 chickens, produce sufficient quantities of manure to fuel a 100 kW biogas plant. Animal farms could benefit substantially from operating small biogas plants which produce energy and high-quality natural fertilizer. Biogas plants are usually built by large farms and agri-food processing enterprises. Biogas can also be effectively generated from treated effluents. There are around 1800 industrial and 1500 municipal wastewater treatment plants in Poland. A typical plant where municipal wastewater is treated mechanically and biologically processes around 60,000 m^3 of wastewater per day and produces around 100 tons of mechanically dehydrated sludge. Biogas produced by anaerobic digestion of sludge has to be desulfurized, which poses an additional problem (Zdeb, 2013). The biogas yield per 1 m^3 of wastewater sludge is estimated at 10–20 m^3.

There are around 700 active landfills in Poland which produce more than 600 million m^3 of methane per year. According to Mirowski et al. (2005), only 30–45% of the existing landfill gas resources are utilized. There are 302 biogas plants in Poland (landfill plants, sewage treatment plants and agricultural biogas plants) with total installed capacity of 233.3 MW, of which 33% falls for agricultural biogas plants. A biogas system fed with landfill gas was described by Sołowiej and Neugebauer (2008) in a practical example. Additionally, the energy potential of landfill gas has been discussed in detail by numerous authors, including Budzianowski (2012), Chmielewski et al. (2013), Chodkowska-Miszczuk and Szymańska (2013), Dach et al. (2014), Igliński et al. (2012), Klimiuk et al. (2010), Markowski et al. (2014), Oleszek et al. (2014), Śliż-Szkliniarz and Vogt (2012), Ziemiński and Kowalska-Wentel (2015).

ECONOMIC AND ENVIRONMENTAL ASPECTS OF BIOGAS PRODUCTION

An agricultural biogas plant is a capital-intensive undertaking. The payback period is very long due to low prices of energy sold to the local grid as well as low prices of renewable energy certificates. Certificates of origin represent property rights to electricity generated by renewable energy sources, they are traded on the Energy Exchange and provide financial support for the development of renewable energy sources.

Selected costs of running an agricultural biogas plant and the estimated payback period in variously-sized plants are presented in Table 3.

Table 3. Estimated payback period in variously-sized agricultural biogas plants
Tabela 3. Oszacowanie przewidywanego okresu zwrotu inwestycji w wybrane biogazownie rolnicze

Plant type/output Rodzaj/moc biogazowni	10 kW	250 kW	2 MW
1	2	3	4
Electricity output [MWh/year] Ilość energii elektrycznej wytworzonej [MWh/rok]	80	2,000	16,000
Heat output [MWh/year] Ilość wytworzonej energii cieplnej [MWh/rok]	83.2	2,080	16,640
Substrate consumption [t/year] Wykorzystane substraty [t/rok]			
distillery wastes – wywar gorzelniczy	343.2	6,630.0	53,040.0
maize silage – kiszonka z kukurydzy	198.0	3,825.0	30,600.0
slurry – gnojowica	66.0	1,275.0	10,200.0
fruit and vegetable processing wastes pozostałości z warzyw i owoców	26.4	510.0	4,080.0
manure – obornik	19.8	382.5	3,060.0
other – inne	6.6	127.5	1,020.0
Total: – Łącznie:	660.0	12,750.0	102,000.0
Costs – Koszty			
Substrate [PLN ‘000] Koszt substratów [tys. zł]			
distillery wastes – wywar gorzelniczy	1.8	35.5	283.7
maize silage – kiszonka z kukurydzy	9.9	191.2	1,530.0
other – inne	0.5	10.2	81.6
Total: – Łącznie:	12.3	236.5	1,895.3
Operating costs* (excluding substrates) [PLN ‘000] Koszty operacyjne* (bez substratów) w [tys. zł]	13.7	413.1	3,304.6
Total: – Łącznie:	38.2	886.5	5,718.2
Proceeds from substrate [PLN ‘000] Przychód z substratów [tys. zł]			
fruit and vegetable processing wastes pozostałości warzyw i owoców	6.8	132.6	1,060.8
other – inne	1.7	33.1	265.2
Total: – Łącznie:	8.5	165.7	1,326.0
Proceeds from the sale of electricity and green certificates [PLN ‘000/year] Przychód ze sprzedaży energii elektrycznej i zielonych certyfikatów [tys. zł/rok]	21.1	525.4	4,203.4
Proceeds from the sale of heat and yellow certificates [PLN ‘000/year] Przychody ze sprzedaży energii cieplnej i żółtych certyfikatów [tys. zł/rok]	9.5	238.7	1,909.6
Total: – Łącznie:	39.1	929.8	7,439.0

Table 3 cont. – Tabela 3 cd.

1	2	3	4
Income – Dochody			
Total proceeds less operating costs [PLN '000/year] Suma przychodów pomniejszona o koszty operacyjne [tys. zł/rok]	13.1	279.9	2,239.0
Subsidies – Dofinansowanie			
Construction costs [PLN million] Koszt budowy [mln zł]	0.5	6	32
Subsidies [%] Dofinnasowanie [%]	50	30	50
Estimated subsidies [PLN million] Przewidywane dofinansowanie [mln zł]	0.25	1.8	16
Construction costs less subsidies [PLN million] Koszty budowy pomniejszone o dofinansowanie [mln zł]	0.25	4.2	16
Payback period – Okres zwrotu			
Estimated payback period [years] Przewidywany okres zwrotu [lata]	19	15	7

* Price of 1 MWh of heat – PLN 46.99 (average price of heat generated from renewable sources of energy in 2014); price of a yellow certificate per 1 MWh of heat – PLN 106.02 (average price for 2014); price of a green certificate per 1 MWh of electricity – PLN 133.55 (average price for the first half of 2015); price of 1 MWh of electricity – PLN 172.22 (average price for Q1 2015).
* Based on the assumption that 70% of annual heat output will be sold.
* The most popular substrates were used in the calculations.
* Slurry – anticipated cost of PLN 0 (by-product of dairy and meat production); maize silage – production cost of PLN 50/t.
Source: own elaboration based on data supplied by the Agricultural Property Agency (www.arr.gov.pl) (retrieved on 16 June 2015), National Fund for Environmental Protection and Water Economy (www.nfosigw.gov.pl) (retrieved on 10 June 2015), TGE (www.tge.pl/pl/155/raporty-miesieczne) (retrieved on 10 February 2015) and the Energy Regulatory Office (www.ure.gov.pl) (retrieved on 12 January 2015).
* Cena 1 MWh ciepła – 46,99 zł (średnia cena sprzedaży ciepła wytworzonego ze źródeł odnawialnych w 2014 r.); cena żółtego certyfikatu za1 MWh ciepła- 106,02 (średnia cena z 2014 r.); cena zielonego certyfikatu 1 MWh – 133,55 zł (średnia z I połowy 2015r..); cena 1 MWh energii elektrycznej – 172,22 zł (średnia cena z I kwartału 2015 r.).
* Zgodnie z założeniem, że 70% rocznej produkcji ciepła zostanie sprzedane.
* Do obliczeń wzięto najpopularniejsze substraty.
* Gnojowica – przewidywany koszt w zł to 0 (produkt uboczny produkcji mleczarskiej i mięsnej); kiszonka z kukurydzy – koszt produkcji 50 zł/t.
Źródło: opracowanie własne, na podstawie danych ARR, (www.arr.gov.pl) (16.06.2015); NFOŚiGW (www.nfosigw.gov.pl) (10.06.2015); TGE http://www.tge.pl/pl/155/raporty-miesieczne (10.02.2015), URE (www.ure.gov.pl) (12.01.2015).

Biogas production contributes to environmental protection by reducing greenhouse gas emissions. The overall reduction in carbon dioxide, methane, and nitrous oxide emissions is expressed in carbon dioxide equivalents (CO_2e). SO_2 and NO_x emissions during biogas combustion are 100-fold and 3-fold lower in comparison with the combustion of fossil fuels. The reduction in greenhouse gas emissions achieved by agricultural biogas plants is estimated at:

- up to 7,700 tons of CO_2e for biogas plants with the output of 1.81 MW_{el}, fueled mainly with chicken manure and distillery wastes,
- up to 3,100 tons of CO_2e for biogas plants with the output of 0.86 MW_{el}, fueled mainly with slurry and maize silage.

Directive 2009/28/EC (Annex V) lists typical and default greenhouse gas emission savings for different biofuel production pathways. The reduction in greenhouse gas emissions is estimated at 80% for biogas from municipal organic waste, 84% for biogas from wet manure, and 86% for biogas from dry manure. According to the Renewable Energy Directive, the estimated reduction in greenhouse gas emissions from a life-cycle analysis of different biofuels accounts for emissions from livestock.

Rutkowski (2011) performed a detailed analysis of a biogas plant with the output of 1 MW_{el}. The total cost of plant construction was PLN 17,178,050. The plant was equipped with a cogeneration unit with the following parameters:

- total electricity installed capacity: 0.999 MW_{el}
- total heat installed capacity: 0.987 MW_t

Estimated output:

- electricity generation: 8 234.9 MWh/year
- heat generation: 29,295 GJ/year (including min. 25,503 GJ of sold heat per year)
- reduction in carbon dioxide emissions: 8002.8 t/year

The reduction in carbon dioxide emissions is correlated with the amount of generated electricity and heat. Turowski and Nowowiejski (2009) conducted an energy analysis in a farm operating a biogas-fueled cogeneration system. Biogas produced by the local biogas plant was used in its entirety to power a combustion engine, and the generated heat and electricity were used by the farm. The energy balance revealed a 10% heat surplus in the cogeneration system.

Sławiński et al. (2012) evaluated the usefulness of online biogas calculators for planning an agricultural biogas plant. They determined the number of defined substrates, cost components programmed in biogas calculators, the methane yield and electricity output of a biogas plant supplied with 50 tons of cattle manure and 50 tons of pig slurry daily. An economic analysis of agricultural biogas plants in Poland was conducted by Kosewska and Kamiński (2008). The construction and operation of agricultural biogas plants was discussed in detail by Myczko et al. (2011). Energy crops, including poplars, can be grown on degraded, dry and nutrient-deficient soils, and they can be used for environmental remediation of contaminated sites.

PROSPECTS FOR THE DEVELOPMENT OF THE AGRICULTURAL BIOGAS SECTOR

In Germany, the minimum price for electricity from renewables is guaranteed by the state over a period of 20 years. German farmers are also entitled to bonus payments for utilizing energy crops, liquid manure, and generating heat from biogas. Biogas producers can apply for low-interest loans, and the value of financial support is determined by the installed capacity of the biogas plant. State support for renewables is regulated by the Renewable Energy Sources Act of 2000 (EEG) which was last amended in 2009 to introduce a system of differentiated tariffs for energy generated from biogas. The system supports fast construction of biogas plants, and the sooner a plant is commissioned for use, the higher the basic guaranteed price (Popczyk, 2011). The Polish support system relies on green and yellow certificates which are traded in an auction system. The auction system promotes the cheapest technologies, and auctions are won by suppliers who quote the lowest prices of energy. The price secured during the auction will remain unchanged for a period of 15 years. This solution hinders the development of biogas plants. The auction system has been tailored to the needs of multiple-fuel combustion systems which are powered by biomass and coal. Contrary to the legislator's claims, Poland will continue to support combined combustion systems to create the impression that EU requirements are being fulfilled. But still, agricultural biogas plants have vast opportunities for development in Poland. Large farms and agri-food processing enterprises can rely on biogas plants to manage slurry, wastes, and byproducts. However, potential investors are discouraged by the high cost of such undertakings and a long payback period. Simplified legislation and greater financial support from the state would speed up the development of biogas technologies in Poland. Agricultural biogas plants should be located in the vicinity of farms or companies supplying the substrate as well as businesses which receive the generated heat and digestate. Plants should be developed at a safe distance from residential areas and, preferably, should be surrounded by trees to prevent protests from local communities (Igliński et al., 2012). In this paper, the potential of the biogas sector was evaluated with the use of Porter's model and the 80–20 rule (80% of the effects come from 20% of the causes), taking into account the factors that influence the attractiveness of biogas plants.

In various stages of development, every sector of the economy is characterized by specific traits (parameters) that influence its attractiveness (value). A sector's attractiveness is evaluated with the use of a point-based system to determine its structural features, resistance to external influences and to supply information about market competition. This method is used to evaluate a sector's prospects and develop the optimal market strategy. A sector's attractiveness is assessed by comparison with other market segments. In Porter's 5 forces analysis, the level of competition within an industry is evaluated based on 5 forces that influence profitability: the threat of established rivals, the threat of new entrants, the threat of substitute products or services, the bargaining power of suppliers, and the bargaining power of customers.

The results of the analysis are presented in Figure 2. A market sector is attractive if it has the features of an ideal sector in the evaluated categories. In theory, an ideal market sector is characterized by 100% attractiveness, but in practice, sectors evaluated above 65% are recognized as attractive.

In Poland, the main obstacles to the development of the agricultural biogas sector include the long and complex process of obtaining a construction permit and connecting the system to the local grid (systems generating energy from renewables are not taken into

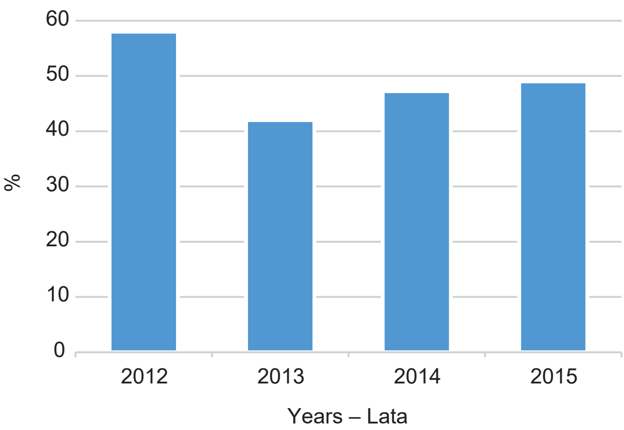

Fig. 2. Rate of changes in the attractiveness of the agricultural biogas sector in Poland
Source: Faculty of Production Engineering, Warsaw University of Life Sciences. The results have been published annually by „Gospodarka Materiałowa i Logistyka" since 2007. Last publication: Szwarc et al. (2015).
Rys. 2. Dynamika zmian atrakcyjności w sektorze biogazu rolniczego w Polsce
Źródło: opracowanie własne dokonane przez zespół WIP SGGW, coroczne wyniki badań publikowane na łamach „Gospodarki Materiałowej i Logistyki" od roku 2007; ostatnia publikacja: Szwarc i in. (2015).

account in local zoning plans), a connection period of up to 150 days, unstable certification system, low certificate prices, unclear regulations regarding the use of digestate as fertilizer, absence of technical facilities and professional support services, weakly developed gas, electricity and heat distribution networks, lack of resources containing information about biogas plants, and protests staged by local communities. The value of certificates of origin changes dynamically every month. A new certificate targeting only agricultural biogas plants has been introduced in September 2016. This is a new support instrument with a value that fluctuates on the Energy Exchange, therefore the relevant payback period is difficult to estimate. These problems and the risk associated with the uncertainty of green energy payments in the future (low prices and short validity of renewable energy certificates) significantly detract from the attractiveness of the biogas sector. The potential of the Polish biogas market remains untapped, and it is similar to that of the German biogas sector in terms of the area under energy crops and substrate production. More than 2000 agricultural biogas plants were to be built in Poland by 2020, but according to the most recent estimates, the number of plants commissioned by the above deadline will not exceed 10% of the planned value.

CONCLUSIONS

- The development of agricultural biogas plants would enable Poland to meet its target of 20% final energy consumption from renewable sources;
- Poland has extensive access to varied substrates for biogas production, including from agricultural sources, wastewater treatment plants, and landfills;
- Due to unstable prices of renewable energy certificates and low prices of green energy generated by agricultural biogas plants, the payback period in biogas plants can exceed 20 years;
- The attractiveness of the agricultural biogas sector in Poland is low and continues to decrease due to complex formal regulations and the risk associated with the uncertainty of green energy payments in the future;
- Energy generated from agricultural biogas reduces greenhouse gas emissions by more than 70% (energy generated from substrates containing 80% manure and 20% maize silage).

ACKNOWLEDGEMENTS

We would like to express our gratitude to Professor Adam Kupczyk for providing access to information resources and making them available for the purpose of this study. We are grateful to Professor Janusz Piechocki, Joanna Stasiak-Panek and Michał Sikora for their valuable comments and suggestions during the preparation of the manuscript. We would also like to thank Aleksandra Poprawska, MA, for translating this manuscript into English.

We are grateful to the Reviewer for all valuable comments and suggestions, which helped us increase the scientific merit of the study.

REFERENCES

ARR (n.d.). Retrieved June 6th 2015 from: www.arr.gov.pl

ARiMR (n.d.). Retrieved June 16th 2015 from: www.arimr.gov.pl

Budzianowski, W. M. (2012). Sustainable biogas energy in Poland: Prospects and challenges. Renew. Sustain. Energy Rev., 1, 16, 342–349.

Chmielewski, A. G., Urbaniak, A., Wawryniuk, K. (2013). Membrane enrichment of biogas from two-stage pilot plant using agricultural waste as a substrate. Biomass Bioenerg., 58, 219–228.

Chodkowska-Miszczuk, J., Szymańska, D. (2013). Agricultural biogas plants – A chance for diversification of agriculture in Poland. Renew. Sustain. Energy Rev., 20, 514–518.

Czyżyk, F., Strzelczyk, M., Steinhoff-Wrześniewska, A., Godzwon, J., Rajmund, A., Kołdras, J., Kaca, E. (2010). Wytyczne w zakresie wykorzystania produktów ubocznych oraz postępowania zalecanego postępowania w rolnictwie i przemyśle rolno-spożywczym, (p. 74–89). Falenty-Warszawa: MRiRW, Instytut Technologiczno-Przyrodniczy.

Dach, J., Boniecki, P., Przybył, J., Janczak, D., Lewicki, A., Czekała, W., Witaszek, K., Rodríguez Carmena, P. C., Cieślik, M. (2014). Energetic efficiency analysis of the agricultural biogas plant in 250 kW_{el} experimental installation. Energy, 69, 34–38.

De Witt (2007). REFUEL Project. Retrieved from: http://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/refuel_planning_the_road_ahead_for_biofuel.pdf

Fugol, M., Prask, H. (2011). Porównanie uzysku biogazu z trzech rodzajów kiszonek: z kukurydzy, lucerny i trawy. Inż. Roln., 9(134), 31–39.

Gołaszewski, J. (2011). Wykorzystanie substratów pochodzenia rolniczego w biogazowniach w Polsce. Postęp. Nauk Roln., 2, 64–94.

IEO (2007). Możliwości wykorzystania odnawialnych źródeł energii w Polsce do roku 2020. Retrieved on 17 June 2015 from: https://www.mg.gov.pl/NR/rdonlyres/AC0AF2CE-748F-4BD7-9DC9-10E94257B732/48364/MozliwosciwykorzystaniaOZE2020.pdf

IEO (2011). Podręcznik dla inwestorów zainteresowanych inwestycją w biogazownie rolniczą. Retrieved on June 16th 2011 from: www.chronmyklimat.pl/download.php?id=67

IERE (2008). Innowacyjna energetyka, rolnictwo energetyczne. Retrieved June 15th 2015 from: www.handelbiomasa.pl/fileadmin/user_upload/PDF_Dateien_Polen/Gesetze/Ustawy_biomasa/Program_INNOWACYJNA_ENERGETYKA_ROLNICTWO_ENERGETYCZNE.pdf

Igliński, B., Buczkowski, R., Iglińska, A., Cichosz, M., Piechota, G., Kujawski, W. (2012). Agricultural biogas plants in Poland: Investment process, economical and environmental aspects, biogas potential. Renew. Sustain. Energy Rev., 16, 4890–4900.

KAPE (2013). Mapa Drogowa Rozwoju Rynku Biometanu w Polsce. Retrieved on April 20th 2015 from: http://www.greengasgrids.eu/fileadmin/greengas/media/Markets/Roadmaps/D4.1_Roadmap_Poland_polish.pdf

Klimiuk, E., Pokój, T., Budzyński, W., Dubis, B. (2010). Theoretical and observed biogas production from plant biomass of different fibre contents. Biores. Technol., 24, 101, 9527–9535.

Kosewska, K., Kamiński, J. R. (2008). Analiza ekonomiczna budowy i eksploatacji biogazowi rolniczych w Polsce. Inż. Roln., 1(99), 189–194.

Markowski, M., Białobrzewski, I., Zieliński, M., Dębowski, M., Krzemieniowski, M. (2014). Optimizing low-temperature biogas production from biomass by anaerobic digestion. Renew. Energy, 69, 219–225.

Mirowski, T., Szurlej, A., Wielgosz, G. (2005). Kierunki energetycznego wykorzystania biomasy w Polsce. Polit. Energ., 8(2), 55–75.

Myczko, A., Myczko, R., Kołodziejczyk, T., Golimowska, R., Lenarczyk, J., Janas, Z., Kliber, A., Karłowski, J., Dolska, M. (2011). Budowa i eksploatacja biogazowi rolniczych (p. 57–73). Poznań–Warszawa: Wyd. Instytut Technologiczno-Przyrodniczy.

NFOSiGW (n.d.). Retrieved June 10th 2015 from: www.nfosigw.gov.pl

Oleszek, M., Król, A., Tys, J., Matyka, M., Kulik, M. (2014). Comparison of biogas production from wild and cultivated varieties of reed canary grass. Biores. Technol., 156, 303–306.

Popczyk, J. (2011). Energetyka rozproszona. Od dominacji energetyki do zrównoważonego rozwoju, od paliw kopalnych do energii odnawialnej i efektywności energetycznej (p. 72–84). Warszawa: Wyd. Polski Klub Ekologiczny Okręg Mazowiecki.
Rutkowski, K. (2011). Analiza wydajności oraz składu biogazu w biogazowi o mocy 1MW. Inż. Roln., 6(131), 173–178.
Sławiński, K., Piskier, T., Bujaczek, R. (2012). Ocena przydatności kalkulatorów biogazowni przy planowaniu budowy biogazowni rolniczej. Inż. Roln., 4(139), 369–375.
Sołowiej, P., Neugebauer, M. (2008). Energetyczne wykorzystanie gazu wysypiskowego na podstawie wybranego obiektu. Inż. Roln., 6(104), 181–185.
Szlachta, J., Fugol, M. (2009). Analiza możliwości produkcji biogazu na bazie gnojowicy oraz kiszonki z kukurydzy. Inż. Roln., 5(114), 275–280.
Szwarc, M., Kupczyk, A., Borowski, P., Sikora, M., Będkowski, W. (2015). Stan aktualny, atrakcyjność i perspektywy sektora biogazu rolniczego w Polsce. Gospod. Mat. Log., 4, 2–13.
Śliż-Szkliniarz, B., Vogt, J. (2012). A GIS-based approach for evaluating the potential of biogas production from livestock manure and crops at a regional scale: A case study for the Kujawsko-Pomorskie Voivodeship. Renew. Sustain. Energy Rev., 1, 752–763.
Turowski, S., Nowowiejski, R. (2009). Analiza układu kogeneracyjnego jako źródła ciepła i energii elektrycznej w modelowym gospodarstwie rolnym. Inż. Roln., 1(110), 331–338.
Zdeb, M. (2013). An Efficiency of H_2S Removal from Biogas via Physicochemical and Biological Methods – a Case Study. Ann. Set Env. Prot. Rocz. Ochr. Środ., 15, 551–563.
Ziemiński, K., Kowalska-Wentel, M. (2015). Effect of enzymatic pretreatment on anaerobic co-digestion of sugar beet pulp silage and vinasse. Biores. Technol., 180, 274–280.

UWARUNKOWANIA ROZWOJU SEKTORA BIOGAZU ROLNICZEGO W POLSCE

Streszczenie. Przedstawiono aspekty prawne regulujące problematykę odnawialnych źródeł energii (OZE), w tym dotyczące sektora biogazu. Scharakteryzowano technologie produkcji biogazu oraz aktualną sytuację sektora biogazu rolniczego w Polsce, z uwzględnieniem zdolności produkcyjnych i stopnia ich wykorzystania, oraz czynniki wpływające na atrakcyjność sektora. Uwzględniono ekonomiczne i ekologiczne aspekty związane z produkcją biogazu, takie jak opłacalność i oddziaływanie na środowisko, w tym również redukcję emisji CO_2. Stwierdzono, że pomimo wielu problemów realną szansę na poprawę sytuacji sektora biogazu w Polsce stwarza wejście w życie ustawy o OZE.

Słowa kluczowe: biogaz, odnawialne źródła energii, atrakcyjność sektora, biomasa

Accepted for print – Zaakceptowano do druku: 15.12.2016