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ECONOMIC AND ENVIRONMENTAL ASPECTS OF THE CULTIVATION OF ENERGY PLANTS IN THE PODLASIE PROVINCE

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ABSTRACT: Dynamic economic growth of EU countries, including Poland, forces to reduce the use conventional energy sources and to replace them with renewable energy sources (RES). Biogas produced in agricultural bio-gas plants becomes one of the most important source of that energy. The most advanced technologies of biogas and electricity from biogas production are found in Germany. In Poland, biogas energy accounts for 2.5% of RES. Basic substrates for agricultural biogas plants are: maize, slurry, manure and other agricultural waste. The emerging biogas plants require stable and reliable cultivation of energy crops, mainly maize silage. In the Podlasie province, 9 agricultural biogas plants with a total capacity of 67.6 MWe were installed in 2014-2016. In order to provide the raw material base for a biogas plant, the area of maize cultivation is estimated at around 3,500 ha. Intensive cultivation of maize (high mineral fertilization, pesticides) in the long term may reduce the utility and biological values of light soils. When locating a biogas plant in the Podlasie province, one should take into account the great landscape values of rural areas and significant areas of protected landscape.

KEY WORDS: biogas, substrates for biogas plant, maize, profitability of plantation, environmental effects, landscape value

Introduction

In the dynamic economic development of the modern world, there is a gradual reduction of energy generation from conventional sources. This is in line with the Kyoto Protocol of 1997, which shows that counteracting the global warming is possible by introducing the new technologies for the production of energy from renewable sources (RES). The EU policy on renewable energy is also closely related to the global strategy for combating the climate change and reducing CO_2 emissions (Piotrowski et al., 2014). The share of energy from renewable sources in the final gross energy consumption in Poland is 7.2%, and in 2020 an increase of this share is assumed to 15%. In the EU countries, the largest share of energy production from renewable sources occurs in Sweden 39.8%, Latvia 34.9%, Finland 28.0%, Austria 23.3%, and Portugal 20.5%. The lowest amount of energy from renewable sources is produced in Luxembourg 0.9%, Great Britain 1.3%, Belgium 2.3%, Netherlands 2.4%, Cyprus 2.9%, and Ireland 3.1% (GUS, 2017).

The basic source of RES are currently solid biofuels that in EU countries constitute 44.6% (table 1). In addition to solid fuels, wind farms and agricultural biogas plants also have a significant share in the production of renewable energy. Biogas obtained in the process of anaerobic biomass fermentation is an important source of renewable energy supported by the European Union and Poland (Directive 2001/77/EC of the European Parliament). In the longer term, however, the share of biomass in renewable energy will be decreasing in favor of solar and wind energy (Banaszuk et al., 2015).

According to the Ministry of Economy, by 2020 it is planned to launch at least one agricultural biogas plant in each commune, the power of which will be in the range of 0.7 to 2 MW. The total power of such biogas plants in Poland in 2020 is estimated at about 2000-3000 MW (*Kierunki rozwoju biogazowni rolniczych*, 2010).

The subject of the study is the assessment of current state of biogas plants and the use of plant raw materials for the production of biogas (mainly maize) in Podlasie province, as well as indication of economic benefits and environmental effects of introducing the large-scale energy crops.

Renewable energy sources in the EU and in Poland

The basic source in the RES structure are currently solid biofuels that in EU countries constitute 44.6%, and in Poland – 73.2% (table 1). Biogas produced from crops and other organic waste accounts for only 7.6% of renewable energy in EU countries. The most energy from biogas is produced in

Germany (20.2%). In Poland, biogas accounts for only 2.5% of energy generated from renewable sources. Opinions about the rapid development of biogas plant networks are different. Not always the energy production in agricultural biogas plants is profitable and competitive in relation to solar and wind energy. Limitations and environmental conditions as well as consequences in the environment have an impact on the slow development of biogas installations (Faber, 2008).

Table 1. Structure of renewable energy sources [%] in some EU countries in 2012-2016

Energy source	Years	EU	Austria	Czech Republic	Finland	France	Netherlands	Lithuania	Germany	Poland	Slovakia	Italy
Solid bio-fuels	2012	48,7	48,3	70,6	79,7	46,0	31,6	82,8	34,1	82,1	55,9	34,4
	2016	44,6	48,1	69,0	76,0	45,2	28,3	82,2	31,0	73,2	55,9	31,2
Solar energy	2012	4,9	2,2	5,3	-	2,1	1,1	0,0	8,9	0,2	2,9	8,4
	2016	6,4	2,9	5,0	-	3,4	2,6	0,4	10,3	0,5	3,1	9,2
Water energy	2012	40,3	40,3	4,9	14,5	24,9	0,2	3,0	5,8	2,1	24,6	17,1
	2016	34,2	34,2	3,6	13,9	21,9	0,2	2,0	4,2	1,7	20,9	16,6
Wind energy	2012	9,7	2,3	1,0	0,4	6,3	10,9	3,9	13,6	4,8	-	5,5
	2016	12,7	4,5	1,2	1,9	8,5	13,5	4,8	17,5	10,4	-	5,4
Biogas	2012	6,7	2,2	10,1	0,6	1,9	7,4	1,0	20,0	2,0	4,3	5,6
	2016	7,6	3,2	14,3	1,0	2,5	6,8	1,6	20,2	2,5	9,3	7,9
Liquid biofuels	2012	6,3	2,8	5,9	2,8	11,7	26,6	9,0	9,3	8,0	10,5	1,8
	2016	6,7	4,8	5,0	4,6	11,8	29,9	7,8	8,5	10,4	9,4	2,9
Geothermal energy	2012	3,1	0,4	-	-	0,9	0,3	0,3	0,3	0,2	0,4	23,5
	2016	3,2	0,4	-	-	1,0	1,2	0,1	0,5	0,2	0,4	23,2
Municipal waste	2012	4,6	1,5	2,2	1,9	6,2	21,8	-	8,1	0,4	1,3	3,8
	2016	4,6	2,0	1,9	2,6	5,7	17,5	1,1	7,7	0,4	0,9	3,6

Source: author's own work based on (GUS, 2016).

Considerable reduction in the agricultural waste deposition on landfills, reduction in methane and nitrogen compounds emissions from stored biomass fermentation, is a positive effect of biogas production. Post-fermentation mass from a biogas production plant may be also a source of a valuable fertilizer for agricultural purposes.

Material and methodology

For preparing the material contained in this paper, data and information from the National Center for Agricultural Support (Rejestr wytwórców

biogazu, www.kowr.pl), Podlasie Agricultural Advisory Center, and the Central Statistical Office, were used. It is problematic to determine data on the area of energy crops, because ARiMR does not keep such records due to the elimination of subsidies for energy crops. Biogas plant owners do not always have full and reliable information about contracted maize crops for biogas plant purposes. In the present study, estimates were made regarding the area of maize cultivation for the needs of biogas plants, assuming that 0.4 ha of maize cultivation is needed per 1 kW of energy (Ginalski, 2014).

Methane fermentation and characteristics of biomass used in biogas installations

Methane fermentation in agricultural biogas plants takes place under anaerobic conditions with the participation of acid-forming bacteria, acetate bacteria and methanogenic bacteria. In the fermentation chamber in the agricultural biogas plant, decomposition of organic matter occurs with the production of biogas, the main component of which is methane CH_4, and CO_2, hydrogen sulfide H_2S, ammonia NH_3 are released in smaller amounts. During anaerobic fermentation, depending on the substrate, approximately 30-60% of the organic matter decomposes most frequently. After the fermentation process, the material (post-fermentation mass) containing minerals remains. The post-fermentation mass is used as agricultural fertilizer. In the natural environment, where organic matter decomposes (boggy and swamp areas), and also in municipal waste landfills, uncontrolled methane emission also occurs (Curkowski, Mroczkowski, 2011).

In agricultural biogas plants, the following substrates are used for the production of biogas: maize silage, perennial plants grown for energy purposes, sugar beets, grasses, natural fertilizers (slurry, manure, bird manure), as well as by-products of the agri-food industry. For the production of biogas, the most effective substrate is biomass with a content of over 30% of organic matter.

According to the Agricultural Market Agency, almost half of the substrate used for biogas production comes from slurry. Most biogas plants using slurry as a substrate occur in the western part of Poland. Depending on local conditions and the specificity of agricultural production, a mixture of several substrates (so-called co-substrates) can be used for biogas plants. The use of co-substrates allows to increase the production of biogas in relation to mono-substrates. Besides, by appropriate selection of the proportion of substrates used, among others, dry matter content and the ratio of basic macronutrients in the mixture obtained can be regulated. The optimal C:N:P:S ratio

should be around 600:15:5:1. It guarantees a proper supply of nutrients to bacteria carrying out the methane fermentation process.

Maize silage and other substrates for biogas plant

In agricultural biogas plants, mostly and in the largest amounts, maize silage and slurry are used as the substrate. In practice it is possible to obtain 15 t·ha^{-1} grain or 25 t DM ha^{-1} (Fugol, Szlachta, 2010). Maize silage is a good substrate for biogas plants due to:

- high yields of green forage (40-45 t·ha^{-1}),
- good properties of green forage for silage,
- high biogas production (450-700 m^3·t DM),
- stabile biogas production in technological process.

Maize (*Zea mays*L.) from grass family (*Poacea*) is a species with multitude of utility features: it adapts to different soil conditions during growing and depending on a cultivar, it has quite high yielding capacity. In technological processes in biogas production plant, it is a good substrate with large biogas production efficiency (table 2). Agrotechnics of maize fir the biogas production purposes is similar to that for fodder, yet high mineral fertilization is applied for the former (up to about 400 kg NPK·ha^{-1}). Applying a high mineral nutrition on light soils with simultaneous tillage, in a longer time perspective can contribute to soil degradation.

Table 2. Technological parameters of maize used as a substrate in a biogas plant

	Seed maturity phase			
	milky	beginning of wax	wax	full
Dry matter [%]	21,9	27,8	32,6	40,1
Organic substance [% DM]	95,7	94,8	94,7	96,3
Green forage yield [t/ha]	45	50	55	45
Biogas efficiency [m^3/ha]	5445	8550	10890	10305

Source: (Podkówka, 2006).

Maize for biogas should be harvested from the field at a content of 30-35% of dry matter (table 3), i.e. at the stage of wax and full grain maturity. In these maturity stages, there are optimal levels of sugars, protein, fat, and raw fiber, and these components are most effectively used for biogas (Michalski, 2002; Podkówka, 2006).

Depending on local conditions and the specificity of plant production in a given region, green forage made of grass (from permanent pastures) and grass from field crops may be used as a substrate for the biogas plant. The best biogas yield is obtained at a content of 30-40% dry matter (so-called preliminarily dried grass). The optimal date for harvesting the green forage intended for silage falls on the stage of the formation of panicles by tall grasses. In this phase of vegetation, the grass contains 17-22% of dry matter. Good results are obtained by ensiling the biomass from grasses dried to a dry matter content of 30-40%. With higher dry matter content in the hay, there are difficulties with its ensiling. If the grass cultivation for the biogas plant is planned, the best results (due to biomass size) are achieve dusing the following species: common ryegrass (*Arrhenatherum elatius* J.et.C.Presl), meadow fox (*Alopecurus pratensis* L.), timothy grass (*Phleum pratense* L.), multiflorous ryegrass (*Lolium multiflorum* Lam.), reed fescue (*Festuca arundinacea* Schreb.), grasshopper (*Dacytlis glomerata* L.), and for light sandy soils, sand reed (*Calamagrostis epigejos* L.Roth. The use of cereal crops (wheat, rye, triticale) as substrates for biogas plant can be debatable due to nutritional and fodder use of these plants.

Selection of plant species for biogas results mainly from the maximization of biomass production volume and obtaining a large income. Often, in the absence of agrotechnical knowledge and with incomplete identification of habitat (soil and water) conditions, large-scale monoculture maize cultivation is introduced. Such crops change the agricultural landscape, reduce the biodiversity of flora and fauna species. The use of valuable, in terms of floristics, permanent grassland as a base for biogas plant can cause significant changes in these valued ecosystems.

Agricultural biogas plants in Poland and in the Podlasie province

As many as 296 biogas plants are registered in Poland (table 3). They use substrates from sewage treatment plants (99 biogas plants), landfills (98 biogas plants) and biomass from agricultural sources (95 biogas plants). Most biogas plants were established in the Mazowieckie and Śląskie provinces, and the smallest in Świętokrzyskie and Opolskie. The most dynamic development of biogas plants has been noted in the last three years and this mainly concerns the creation of agricultural biogas plants. Currently existing 95 agricultural biogas plants have the technical capacity to produce 391 439 352 m^3 of biogas and production of 101,204 MWe (Rejestr wytwórców biogazu, www.kowr.pl). In western provinces, biogas plant substrates are animal waste (slurry and liquid manure), while in eastern provinces, biogas

plants are based on biomass from arable crops, mainly maize silage. According to Michalski (2002), maize silage is characterized by the highest efficiency of biogas production in comparison to other crops.

Table 3. Biogas plants in Poland

Province	The number of individual types of biogas plant installations				Total for provinces
	Biogas from wastewater treatment plants (BGO)	Agricultural biogas plants (BGR) (condition on 16/10/2017)	Biogas from landfills (BGS)	Biogas plants with mixed technology (BGM)	
mazowieckie	10	5	19	-	34
śląskie	16	3	14	1	34
wielkopolskie	7	10	10	-	27
dolnośląskie	9	8	9	1	27
pomorskie	4	9	6	-	19
zachodniopomorskie	4	13	9	1	27
małopolskie	10	2	5	-	17
kujawsko-pomorskie	4	6	7	-	17
warmińsko-mazurskie	6	10	3	-	19
łódzkie	3	4	5	-	12
lubelskie	4	7	2	-	13
podlaskie	5	9	1	-	15
podkarpackie	10	3	3	-	16
lubuskie	2	4	2	-	8
opolskie	3	1	2	-	6
świętokrzyskie	2	1	1	-	4
Total by type	99	95	98	3	295

Source: author's own work based on (National Center for Agricultural Support, www.kowr.pl [17-11-2017]; Woźniak, 2016).

In the Podlasie province, there are currently 9 agricultural biogas plants registered, located in different parts of the province (table 4). The first biogas plant was launched in the Ryboły in 2014. Existing biogas plants with optimal raw material conditions can produce 29.6 million m^3 of biogas, and as a result of its co-generation, about 7.5 MWe can be obtained. The substrates in

the biogas plant in Podlasie are: maize silage, grass, waste from animal production (slurry, bird manure, manure).

Table 4. Agricultural biogas plants in the Podlasie province [condition on 16-10-2017]

Localization	Name of the biogas plant owner	Date of launch	Annual biogas production capacity [$m^3 \cdot year^{-1}$]	Annual power obtained from a co-generator [MWe]	Estimated area of maize cultivation for biogas plant purposes [ha]
Ryboły, commune Zabłudów	Adler Biogaz	2014	4380000	1,000	450
Szepietowo, commune Wysokie Mazowieckie	CHP Energia	2015	4555000	1,200	540
Sokółka, commune Sokółka	Eko-Farmenergia	2015	3338700	0,999	446
Czerwonka, commune Szypliszki	Gospodarstwo Rolne M. Dyczewski	2015	420000	0,100	45
Michałowo, commune Michałowo	Zielona Energia Michałowo	2015	2300000	0,600	270
StaryKornin, commune Dubicze Cerkiewne	Polska Grupa Biogazowa Energetyka	2015	4009120	0,999	446
Dzierżki, commune Poświętne	Polska Grupa Biogazowa Energetyka	2016	4009120	0,999	446
Krasowo Częstki, commune Nowe Piekuty	Green Energy	2016	2221154	0,700	315
Krzywa ,commune Bielsk Podlaski	Polska Grupa Biogazowa Energetyka	2016	4380000	0,999	446
Total			29 613 094	7,596	3404

Source: author's own work based on www.kowr.gov.pl [17-11-2017].

The basic substrate in biogas plants in Podlasie, however, is the maize silage. Currently, there is no precise data on maize cultivation areas contracted by individual biogas plant owners. Also in the ARiMR, there is no data on the area of cultivation of maize for biogas plant purposes. In the present study, a conversion factor of 0.4 ha of maize per 1 kW of energy was adopted for the calculation of maize cultivation area (Woźniak, 2016; Ginalski, 2014). The minimal area of silage maize cultivation for a 1 MW biogas plant should

amount to 400-450 ha. For the needs of Podlasie biogas plants, maize should be grown on 3 404 ha (table 4). According to the Statistical Office in Białystok (Urząd Statystyczny Białystok, 2016), the area of maize cultivation in the main yield in the province in 2016 amounted to 128 300 ha. Maize for biogas plants purposes is 2.6% in the area of its total cultivation.

Economic aspects of the creation of biogas plants in agricultural areas

An important motive for making a decision on the location of a biogas plant is the need to diversify sources of agricultural income. In the market economy and the Common Agricultural Policy of the EU, there is a need to adapt the direction of agricultural production to the market, environmental and climate requirements. Launching the biogas plants, growing energy crops, selling electricity under favorable conditions can be a source of stable and stable income for agricultural producers and local self-governments. Agricultural biogas plants also have a pro-environmental aspect, because they enable management of by-products from agriculture and agri-food processing. The remaining post-fermentation mass can be used as an organic fertilizer, reducing the cost of mineral fertilization (Kowalczyk-Jusko, Szymanska, 2015). The production of maize silage for agricultural biogas plants can be profitable. Research by Szlachta and Tupieka (2013) show that in the production of silage at the level of 41.5 $t \cdot ha^{-1}$ and the sales price of 132 PLN per 1 ton, a profit of PLN 3890 from 1 ha can be achieved. The costs of profit also include an amount of approximately PLN 880, which is a direct subsidy to each hectare.

Under conditions of the Podlaskie province, the emergence of biogas plants in areas of extensive agriculture creates opportunities to stop the outflow of population and labor from such rural areas. Growing crops and maize on arable lands with poor bonitation classes allows to reduce fallow lands. At the same time, there is a fear about the proper agrotechnics.

The liquidation of small farms for social and economic reasons, means that a large part of agricultural land ceases to be agriculturally developed. Such situations take place in many communes of the Hajnówka, Bielsk Podlaski, Bialystok and Sokółka. Taking over small farms by new dynamic owners, creating a larger farm area and diversifying traditional farming directions are important in maintaining proper arable land. One of the sources of constant and stable income in newly established large farms focused on crop production may be the cultivation of maize for biogas plants. With this

change, young producers should pay attention to and adapt to existing climatic and water and soil conditions (Kiryluk, 2016).

Environmental aspects of energy crops in the Podlaskie province

Trends to quickly expand the area of energy crops for agricultural biogas plants may limit the size of other field production. In the case of the Podlaskie province, such a threat should not be expected, because intensive field production was abandoned in large areas, and many arable land of worse bonitation classes is temporarily excluded from production. The limitation in the creation of new biogas plants in the Podlasie province may be unfavorable environmental conditions, large areas of protected areas, occurring in about 40% of the province area. Due to a short lifetime of agricultural biogas plants, there is no reliable information indicating the negative effects of growing energy crops on the environment (Faber, 2008; Jarosz et al., 2013). This assumption does not exclude the thesis that changes in the environment will not occur after a long period of energy crops cultivation. At the stage of biogas plant location, attention should be paid to the existing soil and water conditions of arable land, constituting the target energy base. In special situations and in biogas plants with a capacity above 0.5 MW, it is advisable to prepare an environmental impact (Zarębski, 2013).

In the majority of the area of agricultural land of the Podlasie province, there are not very favorable conditions for the intensive production of cereals, maize and other crop species. The synthetic indicator of the quality of agricultural production space (including soil quality, agroclimate, land relief, water conditions) for the Podlaskie province amounts to 55 points, which is 11.6 points lower than the average for whole Poland (table 6).

Table 5. The synthetic index of agricultural production area in the Podlasie province

Area	Bonitation indicator				Synthetic indicator of the quality of agricultural production space
	The quality and agricultural suitability of soils	agroclimate	land relief	water conditions	
Podlasie province	41,0	7,5	3,7	2,8	55,0
P o l a n d	49,5	9,9	3,9	3,3	66,6

Source: (Biesiacki et al., 2004).

Analyzing the production capacities of the Podlaskie province, it should be noted that soils on the area of 439.3 thousand ha (58.5% of total arable lands), are included in good, weak and very weak rye complexes. It should be borne in mind that introducing the intensive soil and plant cultivation methods in such soil conditions may be inappropriate for economic and environmental reasons. The use of fertilization approximately 400 kg NPK·ha^{-1} on light soils for maize cultivation, will limit the organic matter resources. In such conditions, it will be rational and necessary to use the post-fermentation mass from a biogas plant. Factors limiting the increase in the area of energy crops is also about 30% share of TUZ in the structure of agricultural land. Plowing the meadows and pastures and introducing maize cultivation is inadvisable due to agro-technical reasons and it is inconsistent with the EU's WPR policy of greening.

Energy crops and maize growing due to the high production of plant biomass require a significant amount of water. According to Kowalik and Scalenghe (2015), maize characterized by a transpiration coefficient of 358 kg H2O·kg DM with a minimum yield of 5.5 tons of grain, requires 1,969 m^3 of water in the growing season, i.e. 196 mm of rainfall. If the yield is increased, water consumption will also increase. Light soils in the Podlasie province are characterized by low rainwater retention capacity and low groundwater, therefore irrigation may be necessary for intensive maize cultivation. The use of ploughless cultivations *(stripp-till*) and herbicides in the cultivation of maize for biogas plant causes the reduction of soil utility value and, in particular, reduces its biological activity. Large-scale and multi-annual monocultures of energy crops can reduce the species diversity of plant communities on arable land (Banaszuk et al., 2015; Kiryluk, 2016; Tryjanowski et al., 2011). Elimination of mid-forest afforestation and introduction of maize cultivation on the surface of several dozen or several hectares causes diminution in landscape values of rural areas. The treatment of agricultural areas mainly as places of intensive biomass production in the longer term will result in the emergence of new pests, development of wild boar population and the problem of ASF. In the Podlasie province, rural areas occupy about 60% of its area, and are characterized by a large diversity of habitats, diversified buildings and they are the place of residence and everyday life for about 50% of the province population. Excessive development of modern technologies of agricultural production, elimination of traditional system of fields, gaps, ecotone zones, can significantly diminish the landscape and cultural values of the villages in Podlasie.

Summary and Conclusions

1. Biogas produced mainly in agricultural biogas plants in EU countries constitutes 7.6% of renewable energy sources (RES). In Poland, this proportion is only 2.5%, and in Germany 20.2%.
2. In Podlasie province, according to estimates, it is necessary to cultivate maize for the needs of 9 agricultural biogas plants on the area of approximately 3,500 ha. Currently, the total area of maize cultivation according to GUS data is about 130,000.
3. Agricultural biogas plants in Podlasie province should not be located near natural values areas, as the main raw material base for these biogas plants is intensive cultivation of maize silage.
4. Due to the cultivation of maize in monoculture and the use of high mineral fertilization (about 400 kg NPK·ha^{-1}), there is a gradual reduction in soil biological activity and reduced organic matter content.
5. The elimination of traditional field system, elimination of gaps and unpaved mid-field roads, reduces the landscape values of rural areas in Podlasie.
6. Concentration of large areas of maize cultivation close to compact forest complexes (Puszcza Białowieska) promotes development of wild boar population and the spread of ASF disease, because wild boars find good feed and living conditions in these crops.

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