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ASSESSING THE POSSIBLE USE OF SELECTED TYPES OF RURAL WASTE IN BIOGAS PRODUCTION

Abstract. Poland has a great potential for biogas production based on agricultural waste, among other ingredients. However, until now, waste from rural areas have been considered hard to manage. This paper presents the assessment of possible uses of selected animal and agricultural waste and sewage sludge from domestic sewage treatment plants in the production of biogas in Poland and in the Opolskie voivodeship. The potential for the production of methane, biogas and electric energy was determined based on the quantity of organic waste produced in rural areas. The use of highly fermentative waste in the production of biogas provides an opportunity to reduce the amount of waste and solve the waste management problem. It may also contribute to the development of new investments focused on thermal and electric energy production in rural areas.

Keywords: biogas production, fermentation, waste from rural areas

INTRODUCTION

The growing power demand and the prospect of the depletion of non-renewable energy sources contribute to the fact that biogas production evokes great interest (Othman et al., 2017). The large energetic potential of the national agriculture might constitute an opportunity for the use of the biogas to be developed in Poland. The theoretical raw material potential needed for the production of biogas – that involves agricultural by-products, liquid and solid animal excrements and residues of the agri-food industry – is estimated at 5 billion m^3. However, the actual raw material potential available for the production of biogas based on those products is ca. 1.7 billion m^3 per year (Ministerstwo..., 2010). Figure 1 shows a simplified diagram of a system for biogas production based on different organic waste types.

Animal manure contains highly concentrated nitrogen (N) and phosphorus (P), which causes nutrient imbalance and pollutes the environment. Livestock manure contains some hazardous residues such as growth hormones, antibiotics and heavy metals. The treatment of animal manure and slurries through anaerobic digestion brings benefits in terms of producing high quality fertilizers and reducing odors and microbial pathogens while enabling a sustainable production of biogas as a source of energy (Abdeshahian et al., 2016). Anaerobic digestion is an attractive agri-waste management technique because pollution control, energy recovery and nutrients recycling can be achieved simultaneously. The treatment

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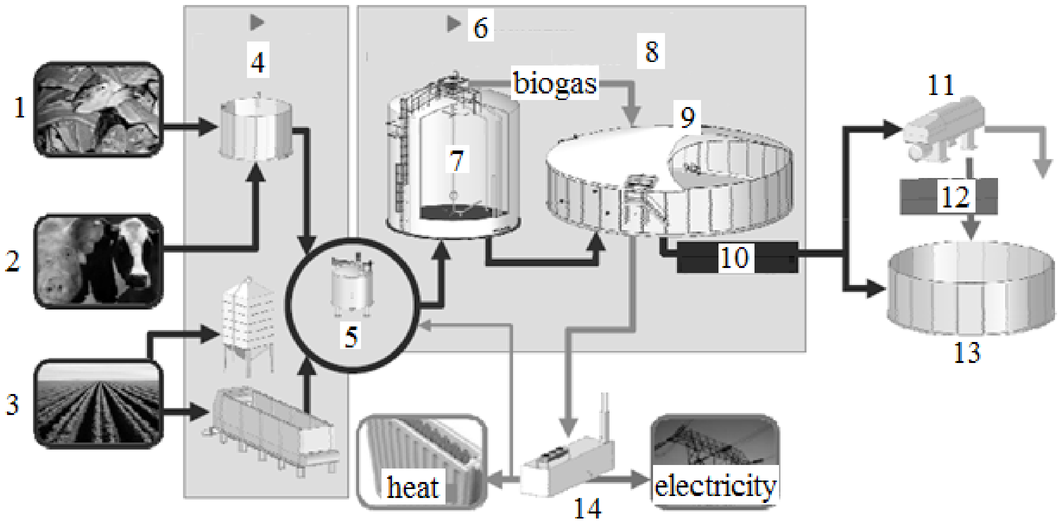

Fig. 1. Agricultural biogas production system. 1 – organic industrial waste, 2 – animal waste, 3 – crops, 4 – substrate preparation, 5 – batcher, 6 – substrate preparation, 7 – digester, 8 – pulp storage, 9 – secondary digester, 10 – digestate, 11 – decanter, 12 – liquid fraction, 13 – pulp treatment, 14 – cogeneration system
Source: Instytut…, 2011.

of animal waste can play a significant role in reducing uncontrolled emissions of methane to the atmosphere, thus reducing the impact of greenhouse gases associated with livestock management (Sun et al., 2016). The use of agricultural waste (difficult to manage otherwise) in the production of biogas allows to deliver large quantities of high-quality environmentally-friendly organic fertilizers in the form of digestate (Ministerstwo…, 2010).

According to data of the National Institute for Agricultural Support (*Krajowy Ośrodek Wsparcia Rolnictwa*, KOWR), there were 86 operators and 96 systems entered to the register of agricultural biogas producers (as at December 31, 2017). In 2017, the production of agricultural biogas (as at March 23, 2018) reached 291.43 million m^3 (41.27 million m^3 more than in 2016). Also, 608.27 GWh of electric energy was derived from agricultural biogas (83.74 GWh more than in 2016) (KOWR, 2018).

The composition of raw biogas varies in function of residue type and anaerobic digestion conditions (the typical raw biogas composition is as follows: CH_4: 40–70% v/v, CO_2: 15–60% v/v, H_2S: 0.005–2% v/v, and trace contaminants (water, siloxanes, volatile organic compounds) (Franco-Morgado et al., 2017). Cebula (2009) claims that agricultural gas mainly includes CH_4 (45–75%), CO_2 (25–55%) and other compounds, such as H_2S (10–30,000 ppm), O_2 (0.01–2.1%) and N_2 (0.01–5.0%). According to data of KOWR (2018) (as at March 23, 2018), in 2017, 3,786,378.63 tons of raw materials were used in the production of agricultural biogas (554,618.44 tons more than in 2016). The raw materials most widely used in the production of agricultural biogas in 2017 are as shown in Fig. 2.

In 2017, the major substrate in the production of agricultural gas was liquid manure, with a share of 21.19%. Other ingredients were fruit and vegetable remains (19.97%), distillery grains (19.94%), maize silage (12.36%) and beet pulp (7.39%).

Despite a number of extensive studies on the production of biogas from waste, new substrates that may be used in, and enhance the effectiveness of, biogas production processes are still being sought. Apart from typical agricultural production waste found in rural areas, there are other types of waste that are difficult to manage, such as waste from onsite sewage treatment plants. The development of individual sewage treatment systems and a growing number of onsite sewage treatment plants in rural areas resulted in a significant increase in the volume of dewatered sewage sludge which might be used as an inexpensive, readily available substrate or co-substrate in biogas production.

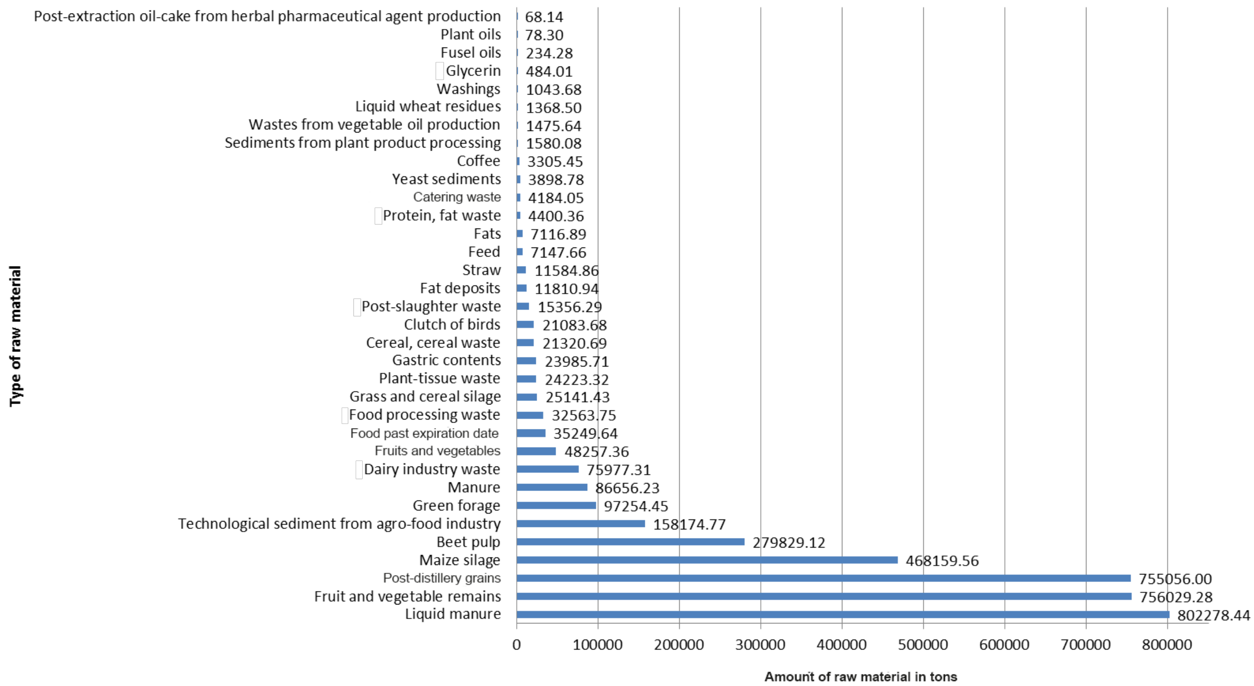

Fig. 2. Raw materials used in the production of agricultural biogas in 2017
Source: own elaboration based on KOWR (2018).

The purpose of this paper is to assess the potential behind and possible uses of selected waste substrates: animal and vegetal waste and dewatered sewage sludge from onsite sewage treatment plants. The use of highly fermentative waste could solve the problem of waste management in rural areas.

MATERIAL AND METHODS

In order to assess the properties of relevance for biogas production, the analysis covered the following types of animal waste: cattle slurry (CS), pig slurry (PS), cow manure (CM), vegetal products; and the following biowaste: maize silage (Ms) and domestic sewage sludge (DSS) from onsite sewage treatment plants in rural areas. In order to determine the potential for biogas production based on waste types considered, the amount of waste produced in the Opolskie voivodeship and in Poland was analyzed. The calculations were based of the following relations:

- annual amount of animal substrates (MS) (Chávez-Fuentes et al., 2017):

$$MS = PA \text{ x } MG \quad (1)$$

- methane production (MP) (Chávez-Fuentes et al., 2017):

$$MP = MS \text{ x } DM \text{ x } OM \text{ x } PCH_4 \quad (2)$$

$$MP = AW \text{ x } DM \text{ x } OM \text{ x } PCH_4 \quad (3)$$

- biogas production (BP) (Chávez-Fuentes et al., 2017):

$$BP = MP \text{ x } \%\ CH_4 \quad (4)$$

- electricity production (EP) (Tańczuk et al., 2016; Chávez-Fuentes et al., 2017):

$$EP = MP \text{ x } GCV_{CH4} \text{ x } \eta_{EL} \quad (5)$$

where: PA: animal population; MG: specific biogas production (weight of animal manure); AW: waste produced per year; DM: dry mass content, OM: organic matter content in waste; PCH_4: potential for methane production; $\%CH_4$: methane content in biogas; GCV_{CH4}: calorific value of methane (9.17 kWh/m^3); η_{EL}: efficiency of electricity production (35%) (Tańczuk et al., 2016).

Tables 1 and 2 show the scope of data required for the calculations, i.e. the number of selected animal species and the characteristics of substrates for the production of biogas.

Table 1. Livestock in Poland and the Opolskie voivodeship

Livestock	Population	
	in Poland	in the Opolskie voivodeship
Cattle in total	5,970,212	122,938
Cows	2,303,455	41,815
Pigs	11,106,716	390,963

Source: own elaboration based on GUS, 2017.

Table 2. Characteristics of selected substrates for biogas production

Substrate name		Dry matter (%)	Organic substances (% d.m.)	Methane production, ($m^3/Mg_{d.m.}$)
Animal farming waste	cattle slurry	9.5	77.4	222.5
	pig slurry	6.6	76.1	301.0
	cow slurry	8.5	85.5	154.0
Agricultural waste	maize silage	32.6	90.8	317.6
Dewatered sewage sludge	domestic sewage sludge	2.65	83.4	100.0

d.m. – dry mass
Source: own elaboration based on Pawlita-Posmyk and Wzorek, 2017; Banaszkiewicz and Wysmyk, 2015; Mazowiecka Agencja Energetyczna, 2009.

The calculations are based on the following assumptions:

- the daily amount of waste is 45 kg per bovine animal, 12.5 kg per swine, and 55 kg per cow,
- there are 203,000 onsite sewage treatment plants in Poland (GUS, 2016),
- there are 5,000 onsite sewage treatment plants in the Opolskie voivodeship,
- dewatered sewage sludge accounts for ca. 1–2% of the treated sewage volume,
- the average water consumption per household member is 2.4 m^3 per month (Regulation of the Minister of Infrastructure of January 14, 2002),
- four-member family: a household with an onsite sewage treatment plant,
- 100 m^3 of biogas is produced from 1 ton of sewage sludge,
- methane content in biogas is 60%,
- silage maize intended for biogas production should meet the same conditions as that intended for green forage for livestock,
- the volume of maize crops grown for green forage in Poland is 29,684,986.9 tons (GUS, 2017),
- the volume of maize crops grown for green forage in the Opolskie voivodeship is 633,234.7 tons (GUS, 2017).

RESULTS AND DISCUSSION

The type, amount and quality of substrates used (dry mass content, methane productivity, origin) determine the volume of biogas production, volume of tanks, machinery and systems size and the output of power generating units used in the production process of electricity and heat (Instytut…, 2011). In order to analyze the physicochemical properties of some examples of rural waste, the relevant data is shown in Table 3.

The main substrate in the production process of agricultural biogas is liquid manure. Depending on animal species, feeding methods and the amount used, it has different qualities. Organic substances vary in decomposition rate and in biogas volume produced as a result of decomposition processes. In the biogas production process, the organic content in waste is an important factor as it affects fermentation and the amount of biogas produced. During microbiological processes, the amount of organic substance decreases over time. As a consequence, so does the amount of methane and the profitability of obtaining and using methane in energy generation. Of all the substrates analyzed, the highest content of organic substances was found in maize silage (90.8% of dry substance).

Maize overtakes other plant species used in biogas production in Germany (90% of content). Silage maize is frequently used because of: its high efficiency in biogas production compared to other grain crops; low costs of obtaining; and no changes in the existing cultivation and harvesting techniques; additionally, it is suitable for long-term storage.

In order to achieve high efficiency of biogas production during methane fermentation, it is necessary to create a favorable environment for the development of microorganisms. Several factors influence the methane

Table 3. Physicochemical properties of selected waste

Feed	TS (%)	VS (%)	pH	C/N ratio	Biogas potential (ml/g VS)	Methane content (%)
Dairy manure	16.91	10.25	8.16	25:1	295	69.1
Horse manure	24.97	18.61	8.24-8.26	23:1	222	70.1
Goat manure	81.63	64.23	8.13	20:1	242	65.8
Chicken manure	67.84	47.50	7.95	10:1	425	61.1
Swine manure	31.02	26.93	7.87	12:1	495	65.3
Maize silage	28.87	94.74	N/A	17.97:1	N/A	N/A
Domestic sewage sludge	N/A	N/A	6.2; 6.8	12.3:1; 14.6:1	N/A	N/A

TS – total solids, VS – volatile solids, N/A – not available.
Source: own elaboration based on Kafle and Chen, 2016; Sun et al., 2016; Pawlita-Posmyk and Wzorek, 2017.

fermentation process (such as the temperature, hydraulic retention time, organic matter load, and indicators of successful progress in the process, such as the reaction, biomass mixing and process-inhibiting substances).

The key parameter affecting the stability of the methane fermentation process is pH. Optimum pH values should be in the range of 6.5 to 8.0 which guarantees a favorable environment for the development of anaerobic bacteria (a pH above 8.5 constitutes a toxic environment) (Dahunsi et al., 2017; Matheri et al., 2017; Pawlita-Posmyk and Wzorek, 2017). Cestonaro et. al. (2015) determined the following pH values: 8.81 for sheep bedding and 8.97 for cattle manure. On the other hand, Zhu et al. (2016) argue that pH values should be 10.0 for maize silage, 7.7 for cattle manure and 8.6 for cow manure. The dewatered sewage sludge from onsite sewage treatment plants has a slightly acidic pH, whereas animal farming waste has an alkaline pH.

In order to provide the optimal conditions for fermentation, biodegradable materials should feature a high C/N ratio. According to Matheri et al. (2017), the optimum conditions in terms of the C/N ratio must be 15–30/1. However, according to Matheri et al. (2017), micro-organisms must have a C/N ratio of 20–30/1. Cestonaro et al. (2015) state that the C/N ratio should be 24/1 for sheep bedding and 15/1 for cattle manure. Matheri et al. (2017) indicate the following C/N ratios: 8/1 for duck dung, 10/1 for chicken dung, 12/1 for goat dung, 18/1 for pig dung, 19/1 for sheep dung, 24/1 for cow dung, 60/1 for maize straw and 70/1 for rice straw. In this analysis, animal farming waste, maize silage and dewatered sewage sludge from onsite sewage treatment plants had an optimum C/N ratio.

The methane content of animal farming waste covered by this analysis is over 60%. In their paper, Popescu and Jurcoane (2015) point out that methane content should be 53% for maize silage and 54% for whole-crop cereals.

Table 4 shows the results of analyses of quantities of waste generated, and the calculated estimated production volumes of biogas and energy in the Opolskie voivodeship and in Poland.

Of all types of waste covered by this analysis, the highest estimated production potential, both on a countrywide basis and in the Opolskie voivodeship, is exhibited by cattle slurry (CS). Conversely, dewatered sewage sludge from onsite sewage treatment plants offers the lowest production potential. The amount of electricity which might be produced from animal farming waste on a countrywide basis and in the Opolskie voivodeship is 55,610,319.2 MWh and 1,176,990.9 MWh per year, respectively. Considering the total amount of all rural waste analyzed, it is possible to produce 64,570,546.3 MWh and 1,368,139.8 MWh of electric energy per year nationally and in the Opolskie voivodeship, respectively. If all the waste was used for biogas production, the amount of waste could be reduced by 225,129,681.9 tons per year nationally and by 5,287,216.2 tons per year in the Opolskie voivodeship. In total, the waste recovered might produce 33,530,947,892.2 m^3 of biogas per year on a countrywide basis and 710,463,614 m^3 of biogas per year in the Opolskie voivodeship.

Table 4. Production of waste, methane, biogas and energy from selected waste substrates

Substrate name		Amount of waste (MS, AW) per year (t)	Biogas production (BP) per year (m^3)	Methane production (MP) per year (m^3)	Electric energy production (EP) per year (MWh)
Animal farming waste	CS[1]	98,060,732.1	26,738,587,549.5	16,043,152,529.7	51,490,498.0
	CS[2]	2,019,256.7	550,598,283	330,358,969.8	1,060,287.1
	PS[1]	50,674,391.8	1,276,827,953.3	766,096,772.0	2,458,787.6
	PS[2]	1,783,768.7	44,945,102.3	26,967,061.4	86,550.8
	CM[1]	46,241,859.1	862,560,958.7	517,536,575.2	1,661,033.6
	CM[2]	839,436.1	15,658,211.8	9,394,927.1	30,153.0
Agricultural waste	Ms[1]	29,684,986.9	4,651,248,613.5	2,790,749,168.1	8,956,909.5
	Ms[2]	633,234.7	99,219,583.0	59,531,749.8	191,067.2
Domestic sewage sludge	DSS[1]	467,712.0	1,722,817.2	1,033,690.3	3,317.6
	DSS[2]	11,520.0	42,433.9	25,460.4	81.7

[1] On a countrywide basis. [2] Opolskie voivodeship.
Source: own elaboration based on Tables 1–2, 2016–2017 Statistics for Poland and calculation assumptions.

CONCLUSIONS

Poland has a great potential for biogas production based on rural waste. In the methane fermentation process, it is possible to use waste which is easily accessible and obtained in an inexpensive manner. This includes animal farming waste (e.g. cattle slurry, pig slurry, or cow slurry), plant waste (e.g. maize silage) and waste from dewatered sewage sludge from onsite sewage treatment plants. Waste types covered by this analysis can be used as substrates or co-substrates in biogas production. As shown by the analyses, the highest estimated production potential (both on a countrywide basis and in the Opolskie voivodeship) is exhibited by cattle slurry (CS). In turn, dewatered sewage sludge from onsite sewage treatment plants offers the smallest potential.

The use of rural waste enables reducing the amount of raw material waste in the voivodeship and on a countrywide basis by 5,287,216.2 tons per year and 225,129,681.9 tons per year, respectively. This could have an effect on the general environmental condition and on the overall energy balance. The selected waste types may generate approximately 1,368,139.8 MWh of electric energy per year in the voivodeship and 64,570,546.3 MWh of electric energy per year on a countrywide basis.

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OCENA MOŻLIWOŚCI WYKORZYSTANIA WYBRANYCH ODPADÓW POCHODZĄCYCH Z OBSZARÓW WIEJSKICH DO PRODUKCJI BIOGAZU

Abstrakt. Polska jest krajem o wysokim potencjale produkcji biogazu, bazującym między innymi na odpadach pochodzących z obszarów wiejskich, które do tej pory uważane były za uciążliwe do zagospodarowania. W artykule dokonano oceny – w skali kraju i województwa opolskiego – możliwości wykorzystania wybranych odpadów pochodzenia zwierzęcego i roślinnego do produkcji biogazu. Przedstawiono analizę właściwości fizykochemicznych wybranych substratów odpadowych oraz przeanalizowano je pod kątem zastosowania w procesie fermentacji metanowej. Oceniono potencjał osadów ściekowych pochodzących z przydomowych oczyszczalni ścieków z terenów wiejskich jako nowego surowca odpadowego. Na podstawie ilości odpadów organicznych wytwarzanych na terenach wiejskich określono potencjał produkcji metanu, biogazu oraz produkcji energii elektrycznej. Wykorzystywanie odpadów o wysokim potencjale fermentacyjnym do produkcji biogazu jest szansą na ograniczenie ilości odpadów i rozwiązanie problemu ich zagospodarowania oraz może się przyczynić do rozwoju nowych inwestycji, umożliwiających wytwarzanie energii cieplnej i elektrycznej na terenach wiejskich.

Słowa kluczowe: produkcja biogazu, fermentacja, odpady pochodzące z obszarów wiejskich