JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2021, 22(3), 111–120
https://doi.org/10.12911/22998993/132426
ISSN 2299–8993, License CC-BY 4.0

Received: 2020.12.16
Accepted: 2021.01.14
Published: 2021.02.01

Database System for Estimating the Biogas Potential of Cattle and Swine Feces in Poland

Agnieszka Wawrzyniak[1*], Andrzej Lewicki[2], Patrycja Pochwatka[3], Piotr Sołowiej[4], Wojciech Czekała[2]

[1] Institute of Technology and Life Sciences, Falenty, Hrabska 3, 05-090 Raszyn, Poland

[2] Department of Biosystems Engineering, Poznań University of Life Sciences, Wojska Polskiego 50, 60-627 Poznań, Poland

[3] Department of Environmental Engineering and Geodesy, University of Life Sciences in Lublin, Leszczyńskiego 7, 20-069 Lublin, Poland

[4] Department of the Electrotechnics Energetics Electronics and Automatics, University of Warmia and Mazury in Olsztyn, Oczapowskiego 11, 10-736 Olsztyn, Poland

[*] Corresponding author's email: a.wawrzyniak@itp.edu.pl

ABSTRACT

Animal biomass is an important substrate in the anaerobic digestion process. The implementation of a waste technology for energy production, such as the production of biogas from animal waste, has been recognized in many countries as one of the best ways to achieve the Sustainable Energy Development Goals. Without a systematic review of resources and accurate estimation of available sources in terms of the amount of potential electricity, it is impossible to manage biomass rationally. The main aim of the article was to present a new tool for assessing the biomass of animal origin and estimating its potential energy through a computer database, which will be widely available in the end of 2020 to show results from the calculation using the database. This tool is configured to enter the data on the developed and undeveloped biomass resources in production of farm animals in rural areas in Poland. Calculations from the database show the biogas potential of swine and cattle manure and slurry in Poland, which is approximately 5.04 billion m^3, with a 60% share of methane in biogas. It is the value of approximately 3.03 billion m^3 of methane. It is worth underlining that slurry and manure are not high-energy substrates; therefore, it is necessary to introduce more energetic substrate streams to improve the biogas plant efficiency.

Keywords: biogas plant; energetic optimization; substrates; manure; slurry; database

INTRODUCTION

Energetic potential of animal biomass

Poland has considerable agro-biomass potential that could pave the way toward sustainable development and achieve the country renewable energy targets by substituting the excessive use of fossil fuels, particularly coal and lignite [Czekała 2018; Zyadin et al., 2018]. The biomass potential in the northern part of Europe among the 9 analyzed countries, such: Denmark, Germany, Estonia, Finland, Latvia, Lithuania, Poland, Sweden and Norway showed that Germany and Poland have the largest technical potential of agricultural biomass, manure and slurry. Sweden has the largest number of pellet production plants, but the highest production was found in Germany, which is the leading biogas producer among the analyzed countries (92% of all biogas plants) [Stolarski et al., 2020]. Biomass is defined as the biodegradable part of products, waste or biological products from agriculture (including plant and animal substances) [Kupryaniuk et al. 2020; Marks et al. 2020], forestry [Czekała et al., 2018a] and industries, including fisheries and aquaculture [Bücker et al., 2020], as well as the biodegradable part of industrial and urban waste [Directive (EU) 2015/1513].

The biomass of animal origin is important as a valuable substrate in the anaerobic digestion process [Czekała et al., 2020]. It should be highlighted that Poland is one of leaders in the European Union in animal breeding [Kozłowski et al., 2019a]. Animal biomass consists mainly of solid and liquid animal waste (manure, slurry), food processing waste and the biomass derived from meat production [Zbytek et al., 2017]. Since 2004, Poland has been at the forefront of the countries generating the largest amount of industrial wastes in the entire European Union [Szymańska et al., 2020]. After proper food processing, waste can be used as raw materials for the production of technical fats, agricultural biogas [Czekała et al. 2018b], biodiesel, building material fillers, fertilizers, as well as for the synthesis of lipolytic enzymes, as feed additives (even for food products). High amounts of organic matter and protein in slaughterhouse wastes make them a viable choice for anaerobic digestion and biogas production [Latifi et al., 2019; Orlando and Borja, 2020]. The implementation of waste to the energy technology such as biogas production from animal waste has been considered as one of the best means to achieve sustainable energy development goals in many developing countries [Munawar et al., 2019]. As an example, it is estimated that 9597.4 $Mm^3 3year^{-1}$ of biogas could potentially be generated from animal waste in Indonesia.

Energetic potential of animal biomass

In the circular bio-economy, effective biomass valorization through the strategic use of resources is essential in terms of generating valuable products, sustainable development, and maximizing the ecological and socio-economic benefits [Bogacka et al., 2017]. In EU legislation biomass is defined as the biodegradable fraction of products, waste, and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste [Directive (EU) 2009/28/EC] or specified biomass as organic, non-fossil material of biological origin that can be used for heat production or electricity generation. It includes wood and wood waste, agricultural crops, biogas, municipal solid waste, biofuels [Eurostat Glossary 2020]. Nowadays, biomass is processed for energy purposes or to produce biofuels [Czekała et al., 2017]. Biofuels are liquid or gaseous transport fuels such as biodiesel and bioethanol which are made from biomass [Directive (EU) 2018/2001].

The biomass for energy purposes can be used in the following forms:

- organic waste: animal feces, meat processing residues;
- liquid biofuels, bioethanol from frying oils;
- biogas from slurry [Lewandowski, 2001].

Among animal biomass, the biomass from meat processing e.g. slaughter of animals, meat boning, cutting, and production of processed meats is the most difficult to manage. Modern infrastructure and advanced technologies, slaughterhouses and meat plants are still classified as the companies that generate waste, and thus significantly contribute to environmental degradation [Mroczek et al., 2019]. The largest amounts of animal excrement that need to be managed are slurry and manure [Esteves Mano et al., 2019]. In the case of biogas produced from animal wastes and by-products from agriculture, horticulture, housekeeping and food industry, the benefits are not limited to the energy balance. The biogas generation ensures also better use of the by-products, in general inconvenient for the environment (odor, contamination of waters) [Grzybek et al., 2015].

Construction of small and cheap agricultural biogas plants, is one of the best directions for disseminating the biowaste valorization technology [Dach et al., 2014; Pochwatka et al., 2020]. Its use in the production of biogas is an environmentally beneficial way not only to reduce this impact, but also to produce energy [Kozłowski et al., 2019b]. Although manure has a low energy value and a low biogas conversion efficiency, it is indicated for use in a co-fermentation process with other biogas substrates. The efficiency of biogas production is influenced by the mixing process and the addition of slaughter residues; the 1% addition of swine placenta increased the production of biogas and methane by 20% [Soares et al., 2020].

Systems for planning the energetic value of animal biomass

A systematic review of comprehensive solution tools to overcome the biomass supply chain (BSC) planning challenges is critical for both academic research and industry [Zahraee et al., 2020]. The combination of market incentives and policy mandates scenario, the production of biomass-based ethanol and electricity increases considerably and could potentially cause substantial changes in the land use practices [Liu et al., 2014]. Radial Basis Function (RBF), as an innovative model dedicated to different silages, is useful tool to estimate the energy value without the necessity of expensive, long-term analysis [Kowalczyk-Juśko et al., 2020a]. The model used basic silage parameters such as: kind of silage, pH, dry matter, organic dry matter, conductivity and fermentation time. The output data in the database sheet contained the cumulative methane production.

A completely different method of estimating biomass originated from Colombia – a four step methodology for estimating the energetic value of biomass. These steps are: using a simple accounting framework, using a solid selection of the probability density function, using probabilistic propagation of uncertainty, and using sensitivity analysis to identify key variables [Salazar-Gonzales et al., 2016].

In Poland, local biomass resources from animal production are estimated by determining the theoretical potential [Siejka et al., 2008]. The theoretical potential of biomass from animal production is determined based on collective summaries concerning the amount of manure obtained from a given type of farm animals, hosted on different systems [Konieczny et al., 2015; Kowalczyk-Juśko et al., 2020b].

The paper aimed to show how to easily and precisely estimate the available sources of agricultural biomass of animal origin in terms of the amount of electricity. Besides, the obtained data were subjected to spatial visualization to indicate the regions of Poland, where the possibility of launching a biogas installation and electricity production is the most profitable. The work combines the scientific and practical aspects which in the future may facilitate the decision-making process regarding the location of a new biogas plant and at the same time avoid investment risks. The article also aimed to show the advantages of estimating the energy potential of the biomass of animal origin, which is a database system developed under the Program: Technology and nature projects for innovative and effective and a low-carbon economy in rural areas.

MATERIAL AND METHODS

Without prior assessment, biomass cannot be effectively managed. Livestock manure management (both solid and liquid fractions) under biorefinery approach seems an inevitable solution for the future sustainable development to meet the circular bioeconomy requirements [Khoshnevisan et al., 2021].

In the years 2016–2020 the Institute of Technology and Life Sciences carried out the program entitled "Technology and nature projects for innovative and effective and a low-carbon economy in rural areas" supported by Polish Ministry of Agriculture and Rural Development [PROGRAM 2016–2020]. The main purpose of the task which is presented in this manuscript is assessment of renewable energy resources in rural areas, in particular biomass, and rationalization of their use. The main product of this task is a computer database, which will be widely available in 2021. The database is configured to enter the data on the resources of developed and undeveloped biomass in the production of farm animals in rural communes in Poland. The database has a tab which concerns animal biomass – feces, but it is planned to be expanded by two tabs: plant production and waste from agri-food processing intended for biogas production.

Data collection

The statistical data are obtained annually from the Agency for Restructuring and Modernization of Agriculture. The data concern livestock production in rural areas divided into communes/counties/voivodships. The obtained data concerns the number of farm animals: swine and cattle, in each voivodeship of Poland.

The system was based on two kinds of mathematical models. Therefore, the calculations can be divided into two stages. In the first stage, the first model was used. This stage involves three steps. The aim of using the model was to calculate the amount of waste generated from keeping a specific group of animals on farms. Livestock can be kept in two systems: bedding and no litter systems. Depending on the type of housing system, the farm produces manure or liquid manure (slurry). The diagram (Figure 1) shows how to use one of the models to calculate the amount of animal excrement based on the number of animals kept in the farms in different regions of Poland.

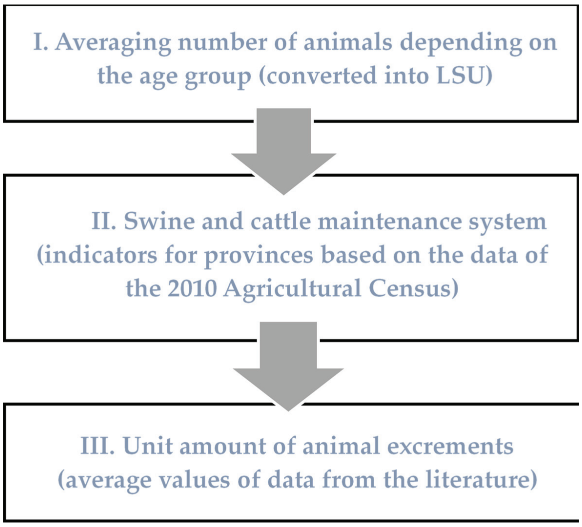

Fig. 1. Model to calculate the amount of animal feces – divided into three steps

The next step was to define the animal keeping system (indicators for provinces based on the data of the General Agricultural Census of the Central Statistical Office). The indicators are shown in Table 1.

In the last step of this stage when indicators are assigned, the amount of excrement is calculated using the first mathematical model: for slurry and for manure. The calculations are based on the literature data.

Description of system functioning (algorithms)

Algorithm for estimating the amount of manure (1).

$$L_o = \sum (x_n \cdot LSU)_n \cdot W_{O_n} \cdot O_n \quad [Mg] \qquad (1)$$

Algorithm for estimating the amount of slurry (2).

$$L_G = \sum (x_n \cdot LSU)_n \cdot W_{G_n} \cdot G_n \quad [m^3] \qquad (2)$$

where: n – type of animals (cattle, swine);
x – livestock of the nth type of animals in the commune [pcs.];
LSU – Livestock Unit is an index of animals per unit [Regulation of the Council of Ministers of June 5th , 2018];
W_G – coefficient of the system of keeping animals in the stands with slatted floor;
W_O – coefficient of the animal keeping system in the stands with a solid floor;
G – average amount of slurry per year per unit of nth type of animals [m^3 / LSU · a];
O – average amount of manure per year per unit of nth type of animals [Mg / LSU · a].

The W_G is calculated from mathematical formula (3).

Tab. 1. Animal keeping system indicators based on: Agricultural Census of the Central Statistical Office [GUS Agricultural Census 2010]

Specification	Animal keeping system in barns		Animal keeping system in piggeries	
Voivodeship	Stands with a slatted floor	Stands with a solid floor	Stands with a slatted floor	Stands with a solid floor
Dolnośląskie	0.334	0.666	0.334	0.666
Kujawsko-pomorskie	0.204	0.796	0.204	0.796
Lubelskie	0.108	0.892	0.108	0.892
Lubuskie	0.176	0.824	0.176	0.824
Łódzkie	0.198	0.802	0.198	0.802
Małopolskie	0.118	0.882	0.118	0.882
Mazowieckie	0.149	0.851	0.149	0.851
Opolskie	0.130	0.870	0.130	0.870
Podkarpackie	0.147	0.853	0.147	0.853
Podlaskie	0.770	0.230	0.770	0.230
Pomorskie	0.462	0.538	0.462	0.538
Śląskie	0.304	0.696	0.304	0.696
Świętokrzyskie	0.127	0.873	0.127	0.873
Warmińsko-mazurskie	0.365	0.635	0.365	0.635
Wielkopolskie	0.343	0.657	0.343	0.657
Zachodniopomorskie	0.312	0.688	0.312	0.688

$$W_G = \left(\frac{S_{BS}}{S_S + S_{BS}}\right)[-] \quad (3)$$

where: S_{BS} – number of stands in the slatted floor animal keeping system for the province;
S_S – number of stands in the littered floor animal keeping system for the voivodeship.

The W_O is calculated from a mathematical formula (4).

$$W_O = \left(1 - \frac{S_{BS}}{S_S + S_{BS}}\right)[-] \quad (4)$$

In the second step, in order to estimate the amount of biogas from animal manure on the example of a monosubstrate biogas plant, the following data were used:

- the amount of animal excrements (results from the estimation of the amount of manure and slurry);
- the amount of biogas (based on the literature data) [Myczko et al. 2011].

RESULTS AND DISCUSSION

The calculations were based on the assumption that the swine manure biogas efficiency was 45 m^3 per Mg of fresh mass, while the swine slurry efficiency was 25 m^3 per Mg. In the case of cattle, the values for manure were 60 m^3, and for slurry – 28 m^3. On the basis of the information on the availability of a given substrate, the total biogas production was calculated for individual voivodeships. The results are shown below.

Swine manure and slurry produced mass and potential of biogas production

The mass of swine manure and slurry calculated on the livestock unit (LSU) number basis has shown a large difference between analyzed voivodeships (Table 2.).

The total amount of yearly swine manure production reaches over 15 million Mg, and this is almost twice more than the slurry production (7.75 million). This situation is abnormal in Western Europe, where the slurry production largely overtakes the generation of manure. However, it is typical in the Eastern European position. The slurry systems are significantly cheaper during their exploitation, comparing to the manure systems, because they need a much lower engagement of human work. Moreover, because working time is quite expensive in Western Europe, as well as the accessibility of workers in Western European agronomy is very limited, the farmers commonly invest in slurry systems in their animal buildings. There is a completely different situation than in Eastern Europe, where human work is a few times cheaper and is much more expensive in the phase of an investment than manure management.

The potential of biogas production from swine manure and slurry in Polish voivodeships has been presented on the map (Figure 2).

Cattle manure and slurry produced mass and potential of biogas production

The availability of manure and cattle slurry exceeds the production potential of swine several times. The total production of cattle manure and slurry exceeds 76 million Mg per year. The leading voivodeships – Mazowieckie, Wielkopolskie, and Podlaskie (Table 3) are characterized by a total production of over 40 million Mg (which is over 50% in relation to the entire territory of Poland). In Poland, the biogas potential of the entire stream of these substrates has been estimated at over 4.1 billion m^3.

The potential of biogas production from cattle manure and slurry in Polish voivodeships has been presented on the map (Figure 3).

Considering the calculations above, it should be stated that the biogas potential of manure and slurry from swine and cattle in Poland is about 5.04 billion m^3, which, assuming a 60% share of methane in biogas, gives the value of about 3.03 billion m^3 of methane. The consumption of natural gas in Poland in 2018 was 19.7 billion m^3. On the other hand, the gas imports to Poland amounted to 13.5 billion m^3 [PGNiG, 2020]. This means that the biogas management of the said substrates is able to cover over 15.3% of the Polish demand for gas and, at the same time, 22.4% of the total import of this fuel. However, taking into account the availability of other waste streams from the agri-food sector and referring it to the potential obtained, for example, in Germany, it seems correct to say that the use of the available waste biomass could ensure the energy independence of Poland – which would become independent of gas imports from abroad.

Tab. 2. Calculation of swine manure and slurry mass and biogas yield

Voivodeship	Swine manure mass (Mg)	Swine slurry volume (m^3)*	Amount of biogas from manure (m^3)	Amount of biogas from slurry (m^3)
Dolnośląskie	233 440	156 094	10 504 819	3 902 357
Kujawsko-Pomorskie	1 702 268	581 679	76 602 039	14 541 984
Lubelskie	851 002	424 865	38 295 095	10 621 626
Lubuskie	372 810	106 173	16 776 471	2 654 314
Łódzkie	1 781 908	586 563	80 185 866	14 664 082
Małopolskie	243 478	43 432	10 956 488	1 085 803
Mazowieckie	2 147 774	501 400	96 649 821	12 534 990
Opolskie	675 551	134 592	30 399 777	3 364 811
Podkarpackie	288 617	66 318	12 987 780	1 657 942
Podlaskie	130 878	584 208	5 889 500	14 605 202
Pomorskie	586 349	671 359	26 385 702	16 783 966
Śląskie	329 375	191 820	14 821 871	4 795 497
Świętokrzyskie	471 353	91 427	21 210 871	2 285 674
Warmińsko-Mazurskie	723 488	554 484	32 556 966	13 862 109
Wielkopolskie	3 796 751	2 642 893	170 853 782	66 072 323
Zachodniopomorskie	677 393	409 587	30 482 691	10 239 664
TOTAL:	15 012 435	7 746 894	675 559 540	193 672 343

* It was assumed that 1 m^3 of animal slurry has a weight 1 Mg

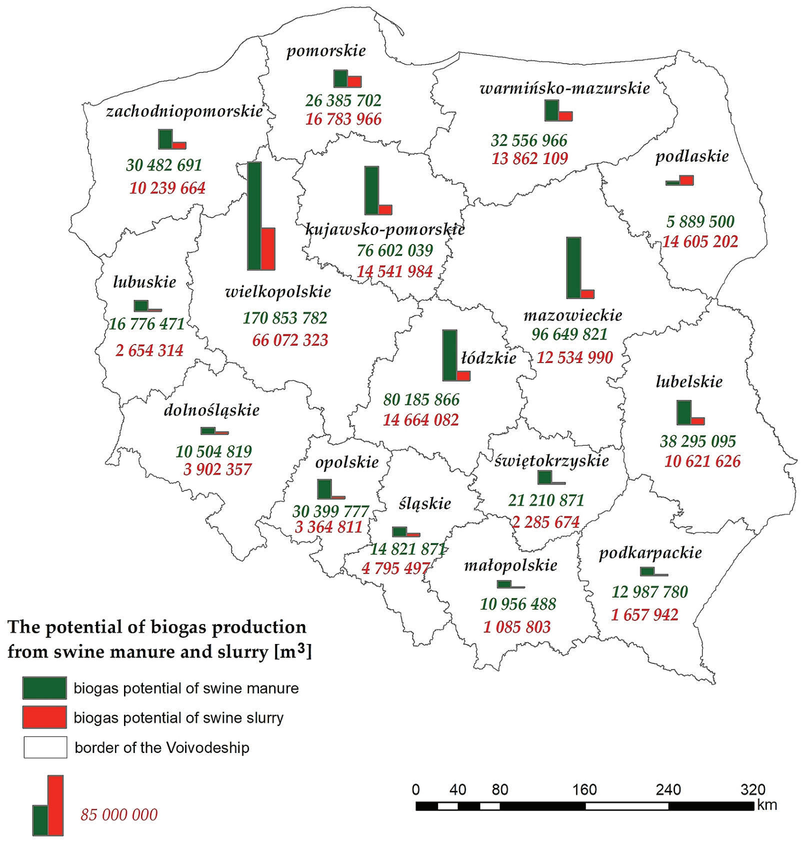

Fig. 2. The potential of biogas production from swine manure and slurry in Poland

Tab. 3. Calculation of biogas yield from cattle manure and slurry

Voivodeship	Cattle manure mass (Mg)	Cattle slurry volume (m^3)*	Amount of biogas from manure (m^3)	Amount of biogas from slurry (m^3)
Dolnośląskie	1 219 450	69 513	73 166 972	1 946 372
Kujawsko-Pomorskie	5 426 350	315 911	325 581 029	8 845 510
Lubelskie	4 059 764	345 512	243 585 861	9 674 332
Lubuskie	1 021 850	16 548	61 311 007	463 349
Łódzkie	4 857 030	679 805	291 421 828	19 034 550
Małopolskie	1 804 330	334 287	108 259 810	9 360 048
Mazowieckie	12 256 535	2 838 759	735 392 102	79 485 260
Opolskie	1 335 638	152 755	80 138 301	4 277 136
Podkarpackie	945 002	124 616	56 700 107	3 489 237
Podlaskie	10 081 290	3 339 454	604 877 417	93 504 702
Pomorskie	2 295 210	317 512	137 712 580	8 890 349
Śląskie	96 974	1 890 988	5 818 424	52 947 655
Świętokrzyskie	1 762 034	123 652	105 722 033	3 462 242
Warmińsko-Mazurskie	4 235 675	1 892 576	254 140 520	52 992 125
Wielkopolskie	10 725 376	768 520	643 522 585	21 518 563
Zachodniopomorskie	1 194 621	136 627	71 677 262	3 825 554
TOTAL:	63 317 129	13 347 035	3 799 027 837	373 716 986

* It was assumed that 1 m^3 of animal slurry has a weight 1 Mg

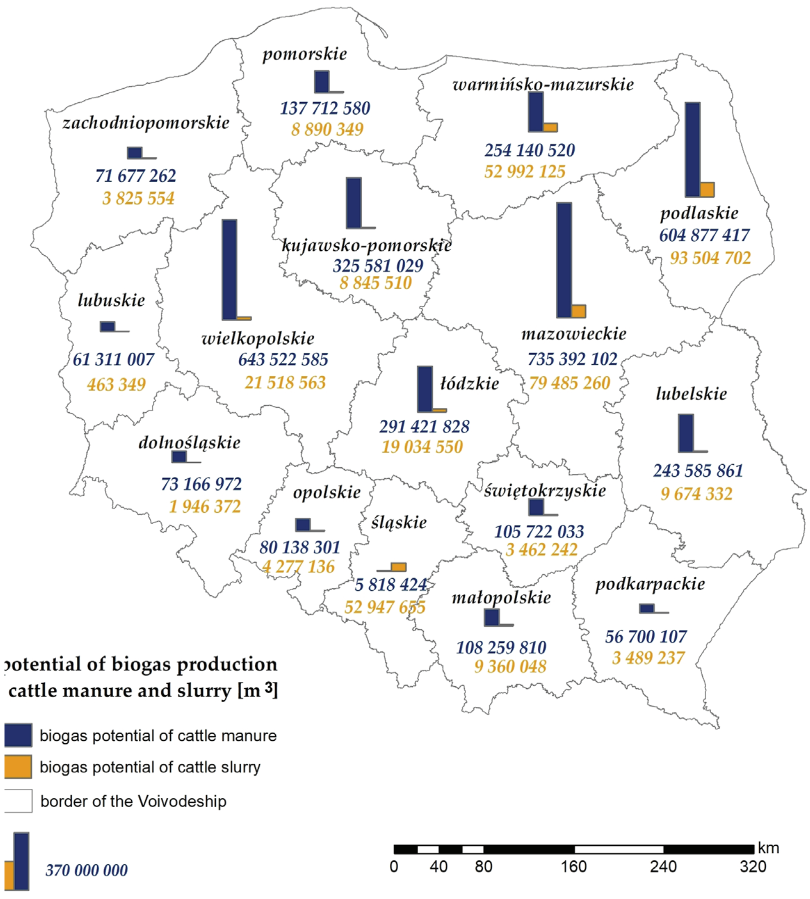

Fig. 3. The potential of biogas production from cattle manure and slurry in Poland

CONCLUSIONS

Due to the extensive agriculture, Poland is characterized by a large availability of organic waste streams that can be utilized for energy. Unfortunately, due to the lack of stable support for the development of this renewable energy sector in Poland in previous years, as of today, only 116 agricultural biogas plants are active (as of October 30, 2020). The annual capacity of these installations for the production of agricultural biogas is approximately 473 million m^3. It is only 9.4% the calculated potential of available manure and slurry.

Another major problem of Polish agriculture is its fragmentation. This state of affairs makes the investment process related to a biogas plant's construction and operation difficult.

Additionally, it should be remembered that manure and slurry, despite their high availability, are not very energetic substrates. For this reason, the installations fed only with these substrates would have to be characterized by large volumes, which increases the investment cost and worsens the economic balance of the project. On the other hand, the legal regulations forcing farmers to store these substrates in winter, force the investments related to the construction of tanks necessary for their storage. This enables the development of two types of installations – either very simple and cheap, owing to which the economic balance of such a project will be positive, or more advanced installations, focused on maximizing the production per cubic meter of the fermentation tank. However, it is then necessary to introduce more energetic substrate streams to improve the efficiency of the installation. In this variant, the slurry is mainly used as a diluent for substrates with a higher dry matter content, characterized by higher energy, while the manure is processed by the installation, making it possible to use its energy potential, improving its fertilizing properties [Czekała et al., 2020] and allows its lawful storage in the winter when it cannot be applied to the fields.

Acknowledgements

The research presented in this work was financed by the Program "*Technology and nature projects for innovative and effective and a low-carbon economy in rural areas 2016–2020*" under contract: U. No. 154/2016 of the Council of Ministers on the basis of the Public Finance Act. The contractor of the Program is the Institute of Technology and Life Sciences on behalf of the Ministry of Agriculture and Rural Development.

REFERENCES

1. Batidziari B., Smeets E.M.W., Paaij A.P. 2012. Harmonising bioenergy potential assessments. Renewable and Sustainable Energy Reviews, 16, 6598–6630 doi: 10.1016/j.rser.2012.09.002.
2. Bogacka M., Pikoń K. 2017. Biomass as fuel. In: Kotowicz J.; Pikoń K. (Eds) Contemporary problems of energy. Gliwice, 121–132 (in Polish).
3. Bücker F., Marder M., Peiter M.R., Lehn D.N., Esquerdo V.M., A. de Almeida Pinto L., Konrad O. 2020. Fish waste: An efficient alternative to biogas and methane production in an anaerobic mono-digestion system. Renewable Energy, 147, 798–805, doi:10.1016/j.renene.2019.08.140.
4. Czekała W. 2018. Agricultural Biogas Plants as a Chance for the Development of the Agri-Food Sector. Journal of Ecological Engineering, 19(2), 179–183. doi: 10.12911/22998993/83563.
5. Czekała W., Bartnikowska, S., Dach, J., Janczak D., Smurzyńska A., Kozłowski, K., Bugała A., Lewicki, A., Cieślik, M., Typańska, D., Mazurkiewicz J. 2018. The energy value and economic efficiency of solid biofuels produced from digestate and sawdust. Energy, 159, 1118–1122, doi:10.1016/j.energy.2018.06.090.
6. Czekała W., Cieślik M., Janczak D., Czekała A., Wojcieszak D., 2018. Fruit and vegetable waste from markets as a substrate for biogas plant. 18th International Multidisciplinary Scientific Geoconference SGEM 2018. Conference Proceedings vol. 18, Energy and Clean Technologies Issue: 4.3, 473–478, doi: 10.5593/sgem2018V/4.3/S11.056.
7. Czekała W., Lewicki A., Pochwatka P., Czekała A., Wojcieszak D., Jóźwiakowski K., Waliszewska H. 2020. Digestate management in polish farms as an element of the nutrient cycle. Journal of Cleaner Production, 242, 118454. doi:10.1016/j.jclepro.2019.118454.
8. Dach J., Boniecki P., Przybył J., Janczak D., Lewicki A., Czekała W., Witaszek K., Carmona Cesar P., Cieślik M., 2014. Energetic efficiency analysis of the agricultural biogas plant in 250 kWe experimental installation, Energy, 69, 34–38 doi: 10.1016/j.energy.2014.02.013.
9. Directive (EU) 2009/28/EC of the European Parliament and of the Council of 23 April 2009o n the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC Available online: https://eur-lex.europa.eu/legal-content/EN/

TXT/PDF/?uri=CELEX%3A32009L0028&from=EN (Accessed: 16-Nov-2020).

10. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Available online: https://eurlex.europa.eu/legalcontent/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG (Accessed: 16-Nov-2020).
11. Directive EU 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32015L1513&from=EN (Accessed: 16-Nov-2020)
12. Esteves E., Herrera Naranjo A., Esteves Pecanha V., Morgado C., 2019. Life cycle assessment of manure biogas production: A review. Journal of Cleaner Production, pp. 411–423 doi: 10.1016/j.jclepro.2019.02.091.
13. Eurostat Glossary [Online]. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Biomass (Accessed: 16-Nov-2020)
14. Grzybek A., Pawlak J., 2015. Potential and use of renewable energy sources in agriculture. Wydawnictwo ITP Falenty (in Polish).
15. GUS Agricultural Census 2010. Livestock and selected elements of animal production method, 1390.
16. Khoshnevisan B., Duan N., Tsapekos P., Awasthi M., Liu Z., Mohammadi A., Angelidaki I., Tsang CW. D., Zhang Z., Pan J., Ma Lin; Aghbashlo M., Tabatabaei M., Liu H. A., 2021. Circular review on livestock manure biorafinery technologies: Sustainability, challenges, and future perspectives. Renewable and Sustainable Energy Reviews, 135, 11033 doi: 10.1016/j.rser.2020.110033.
17. Konieczny R., Fedko M., Łaska B., Golimowski W., 2015. New models of biomass resource monitoring and available technologies for its conversion in RES installations (in Polish).
18. Kowalczyk-Juśko A., Pochwatka P., Zaborowicz M., Czekała W., Mazurkiewicz J., Mazur A., Janczak D., Marczuk A., Dach J. 2020. Energy value estimation of silages for substrate in biogas plants using an artificial neural network. Energy, Vol. 202, July 117729. doi: 10.1016/j.energy.2020.117729 .
19. Kowalczyk-Juśko A., Mazur K., Maciąg M., Pochwatka P., Listosz A., Mazur A. 2020. Estimation of Potential of Agriculture Biogas Production in Biała Podlaska County (Poland). Journal of Ecological Engineering 21, 156–162, doi:10.12911/22998993/126986.
20. Kozłowski K., Dach J., Lewicki A., Malińska K., Carmo I., Czekała W. Potential of biogas production from animal manure in Poland. Archives of Environmental Protection, 2019. 45, 3, 99–108, doi: 10.24425/aep.2019.128646.
21. 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, doi:10.1016/j.energy.2019.06.179.
22. Kupryaniuk K., Oniszczuk T., Combrzyński M., Czekała W., Matwijczuk A. 2020. The Influence of Corn Straw Extrusion Pretreatment Parameters on Methane Fermentation Performance. Materials (Basel), 13, 3003, doi:10.3390/ma13133003.
23. Latifi P., Karrabi M., Danesh S. 2019. Anaerobic co-digestion of poultry slaughterhouse wastes with sewage sludge in batch-mode bioreactors (effect of inoculum-substrate ratio and total solids) Renewable and Sustainable Energy Reviews, 107, 288–296 doi:10.1016/j.rser.2019.03.015.
24. Lewandowski W.M. 2001. Proecological renewable sources. Wydawnictwa Naukowo-Techniczne, Warszawa (in Polish).
25. Liu T., McConkey B., Huffman T., Smith S., MacGregor B., Yemshanow D., Kulshreshtha S. Potential and impacts of renewable energy production from agricultural biomass in Canada. Applied Energy, 2014, 130, 222–229 doi: 10.1016/j.apenergy.2014.05.044.
26. Marks S., Dach J., Garcia-Morales J.L., Fernandez-Morales F.J. 2020. Bio-Energy Generation from Synthetic Winery Wastewaters. Applied Sciences,10, 8360, doi:10.3390/app10238360.
27. Mroczek K., Kucharyk S., Rudy M., Mroczek R. J. 2019. Options for utilisation of waste from meat industry in compliance with the rules of bioeconomy. Polish Journal for Sustainable Development, 23(2) (in Polish).
28. Munawar K., Barawi Ali M., Heryanto R., Rizalie A. 2019. Waste to energy technologies: The potential of sustainable biogas prouction from animal waste in Indonesia. Renewable and Sustainable Energy Reviews, 105, 323–331, doi: 10.1016/j.rser.2019.02.011.
29. Myczko M., Myczko R., Kołodziejczyk T., Golimowska R., Lenarczyk J., Janas Z., Kliber A., Karłowski J., Dolska M. 2011. Construction and operation of agricultural biogas plants. Instytut Technologiczno-Przyrodniczy. Poznań (in Polish).
30. Orlando M-Q., Borja V-M. 2020. Pretreatment of Animal Manure Biomass to Improve Biogas Production: A Review. Energies, 13(14), 3573; doi:10.3390/en13143573.
31. PGNiG 2020 [Online]. Available online: http://en.pgnig.pl/news/-/news-list/id/pgnig-less-gas-from-russia-lng-imports-on-the-rise/newsGroupId/1910852?changeYear=2020&currentPage=1

(Accessed: 19-Nov-2020).

32. Pochwatka P., Kowalczyk-Juśko A., Sołowiej P., Wawrzyniak A., Dach J., 2020. Biogas Plant Exploitation in a Middle-Sized Dairy Farm in Poland: Energetic and Economic Aspects. Energies. 2020, 13, 6058, doi: 10.3390/en13226058.
33. PROGRAM 2016–2020 [Online]: Available online: https://www.itp.edu.pl/pw/PW2016/zadanie-1.html. (Accessed: 16-Nov-2020) .
34. Regulation of the Council of Ministers of June 5th, 2018 on the adoption of the Action Program to reduce water pollution with nitrates from agricultural sources and to prevent further pollution.
35. Salazar-Gonzales M., Venturini M., Poganietz W., Finkenrath M., Spina Ruggero P., 2016. Methodology for improving the reliability of biomass energy potential estimation. Biomass and Bioenergy, 2016, 88, 43–58, doi: 10.1016/j.biombioe.2016.03.026.
36. Siejka K., Tańczuk M., Trinczek K. 2008. The concept of the estimating the energy potential of biomass of an example of the selected commune Opolskie Voivodeship. Agricultural Engineering 6(104), 167–173 (in Polish).
37. Soares C., Viancelli A., Michelan W., Sbardelloto M., Camargo A., Vargas L.P.G., Fongario G., Treichel H. 2020. Biogas yield prospection from swine manure and placenta in real-scale systems on circular economy approach. Biocatalysis and Agricultural Biotechnology, 25, 101598, doi: 10.1016/j.bcab.2020.101598.
38. Stolarski J. M., Warmiński K., Krzyżaniak M., Olba-Zięty E., Akincza M. 2020. Bioenergy technologies and biomass potential vary in Northern European countries. Renewable and Sustainable Energy Reviews 133, 110238, doi: 10.1016/j.rser.2020.110238.
39. Szymańska I., Brzeski M., Żbikowska A. 2020. Waste management of the food industry in Poland with particular emphasis on fatty waste, Food Industry, 74(8), 23–27, doi: 10.15199/65.2020.8.3.
40. Zahraee S., Shiwakoti N., Stasinopalos P. 2020. Biomass supply chain environmental and socio-economic analysis:40- years comprehensive review of methods, decision issues, sustainability challenges, and the way forward. Biomass and Bioenergy, 142, 105777, doi: 10.1016/j.biombioe.2020.105777.
41. Zbytek Z., Adamczyk F. 2017. Possibilities of using solid biomass. Part 1. Legal conditions and division of solid biomass. Forest Horticultural Agricultural Technique, Vol. 2/2017 (in Polish).
42. Zyadin A., Natarajan P., Latva-Kayra P., Igliński B., Igliński A., Trishkin M., Pelkonem P. Papinnen. 2018. Estimation of surplus biomass potential in southern and central Poland using GIS application. Renewable and Sustainable Energy Reviews, 89, 204–215, doi: 10.1016/j.rser.2018.03.022.