Decision Making in Manufacturing and Services
Vol. 16 • 2022 • pp. 19–31

Identifying Key Factors for Successful Development of Agricultural Biogas Plants in Poland

Grzegorz Ginda*, Marta Szyba*

Abstract. In Poland, the potential for biogas production is high. It is an important source of renewable energy and contributes to reducing methane emissions (a greenhouse gas). In this article, the implementation of an agri-gas plant-construction program was evaluated in individual voivodeships based on materials from the National Agricultural Advisory Center (KOWR), the literature, and statistical data. Based on the collected data, it was concluded that the most meaningful factors for the successful development of Polish agricultural biogas plants were biogas-production technology, substrate availability, energy prices from renewable energy sources, waste-disposal costs, the population density in a commune, and the allocation of places in local spatial-development plans. The DEMATEL technique was used to identify the key developmental factors. The results of the study provide useful information for both governments and local authorities in their searches for effective ways to drive the sector's development.

Keywords: agricultural biogas plants, development, factor, identification, pairwise comparison, DEMATEL

Mathematics Subject Classification: 90B50

JEL Classification: O13, Q59

Submitted: February 2, 2022

Revised: December 31, 2022

1. INTRODUCTION

In act *Polityka Energetyczna Polski do 2040 r. (Poland's Energy Policy until 2040)* (Ministerstwo Energetyki RP, 2019), three goals were formulated; these were "energy security, competitiveness and energy efficiency, and the limited impact of energy on the environment." The last goal is closely related to the development of

---

*AGH University of Science and Technology, Faculty of Management, Krakow, Poland, e-mails: gginda@agh.edu.pl, mszyba@agh.edu.pl

DOI: https://doi.org/10.7494/dmms.2022.16.2785

renewable energy sources. It is assumed that, by 2040, this should constitute 28.5% of the share of energy from renewable energy sources (RES) in the gross final energy consumption (and 39.7% in the electricity sector). Renewable energy sources in the power industry are solar energy, wind energy, water energy, biomass, and biogas. Due to limited hydropower resources and difficulties in controlling the supply of wind and solar energy, "the use of biogas will be particularly useful in the combined production of electricity and heat. The advantage is the ability to store energy in biogas, which can be used for regulatory purposes. In terms of general economic use, biogas constitutes additional added value because it enables the management of particularly burdensome waste (e.g., animal waste, landfill gases)" (Ministerstwo Energetyki RP, 2019). The largest biomass resources can be found in agriculture and agri-food processing. These resources are breeding waste (pig and cattle manure, poultry manure), slaughter waste, fruit- and vegetable-processing waste, and distillery waste.

In 2010, the Council of Ministers adopted a document entitled *Kierunki rozwoju biogazowni rolniczych w Polsce w latach 2010–2020 (Directions of development of agricultural biogas plants in Poland in 2010–2020)* (Rada Ministrów RP, 2010). Due to the high costs of the installations that are meant for biogas production, the energy that is potentially produced from it was granted a so-called *blue certificate*, which is more costly than the *green certificates* from other renewable energy sources (e.g., wind farms). The mentioned document assumed that, by 2020, there should be one agri-gas plant in each commune on average (Rada Ministrów RP, 2010). This program will not be implemented because there are only 105 biogas plants that are currently operating; these have the collective capacity to produce approximately 443 mln m^3 of biogas, and the installed capacity of their electricity generators is 109.694 MW (Dyrektor Generalny KOWR, 2019).

In this article, implementations of the agri-gas plant-construction program were evaluated in the individual voivodeships based on materials from the Krajowy Ośrodek Wsparcia Rolnictwa (KOWR) (National Agricultural Advisory Center), the literature, and statistical data. It seems that the existing disproportions were influenced by factors such as the availability of biomass, renewable energy prices, waste-disposal costs, population densities in the voivodeships and communes, and the existence of local spatial development plans in the communes. The DEMATEL (Decision Making Trial and Evaluation Laboratory) method was used to assess the impacts of the factors that were mentioned above on the number of biogas plants; the result of its use was the construction of a diagram that illustrated the strengths of the impacts of the individual factors. An analysis of this diagram may be useful when looking for locations for additional agri-gas plants.

2. AGRICULTURAL BIOGAS

Biogas is produced as a result of the anaerobic fermentation of organic substances under natural conditions (peat bogs, landfills) or in installations that are intended for this purpose. Its basic component is methane, whose contents range from 40–85%. The remaining ingredients are carbon dioxide (in amounts of 16–48%), nitrogen (0.6–7.5%), hydrogen sulfide, and water vapor (Majoch & Jabłońska, 2013). The biogas that is produced in installations is most often burnt in cogeneration units that produce both electricity and heat. Before its combustion in such units, the biogas must be cleaned of its hydrogen sulfide, carbon dioxide, and water vapor.

Because agricultural biogas does not differ in its composition from the biogas from other sources, its name is related to the substrates from which it is produced. In the act *Kierunki rozwoju biogazowni rolniczych w Polsce w latach 2010–2020* (Rada Ministrów RP, 2010), it was defined as: "fuel obtained from the fermentation process of methane from agricultural raw materials, agricultural by-products, liquid or solid animal excrement, by-products or residues from the processing of agricultural, or forest biomass products of origin, excluding the gas that is obtained from the raw materials from sewage-treatment plants and landfills." The substances that were listed in the definition were called substrates.

Agricultural biogas is produced in agri-gas plants (biogas plants) that cover areas of 1–2 ha – the main facilities of which are as follows (Podkówka, 2012):

- storage of solid and liquid substrates,
- pre-mix tank,
- charging hopper,
- fermentation chamber,
- biogas-storage tank,
- biogas-purification device,
- gas-combustion cogeneration unit building,
- control and measurement equipment,
- digestate separation and thickening device.

The biogas that is produced in the fermentation chamber is pumped through pipelines to gas tanks and cogeneration units; most of the time, it is completely burnt on-site in cogeneration units. The generated electric current is sent to the power grid, and the heat is used to heat the substrates (approximately 30%), heating the biogas plant rooms, and selling it (if there are recipients). After being tested for its suitability for fertilizing soils and plants, the digestate is sold as fertilizer, thus providing additional income (Kowalczyk-Juśko, 2014). Digestate is also used in Denmark but not in Norway (Lyng et al., 2020).

The most common substrates in agricultural biogas plants are waste that is harmful to the environment and requires expensive disposal. The disposal of such waste includes slurry, fruit and vegetable residues, distillery stillage, technological sludge from the agri-food industry, re-waste from food processing, and expired food. In 2011, biogas plants processed 469,000 Mg of this waste (including 266,000 Mg of slurry). In 2016, they processed 3,224,000 Mg of waste (including 775,000 Mg of slurry), 665,000 Mg of fruit and vegetable residues, and 476,000 Mg of distillery vinasse. Biogas plants on agricultural farms also used corn silage. In 2011, 109,000 Mg of corn silage was used (23.2% of the mass of all of the substrates); in 2016, this number was 439,000 Mg (13.6%) (Gradziuk, 2017). The data that is quoted shows that, unlike agricultural biogas plants in Germany, Polish agricultural biogas plants use silage to a small extent and, therefore, do not constitute competition for feed production.

Since the waste that is used to produce biogas emits unpleasant odors and the fact that numerous facilities of common agri-gas plants occupy areas of 1–2 ha (Podkówka, 2012), they must be located away from human populations.

3. AGRI-GAS PLANTS IN POLAND

On January 1, 2011, nine biogas plants were entered into the Register of Agricultural Biogas Producers, which is kept by the National Center for Agricultural Support. In total, 14 biogas plants were registered in 2011. The greatest numbers could be found in the following voivodeships: Zachodniopomorskie (5), and Pomorskie (4). A single biogas plant was registered in each of the following voivodeships: Dolnośląskie, Lubelskie, Lubuskie, Śląskie, and Wielkopolskie voivodeships.

Table 1. *Number of agri-gas plants in voivodeships – own study based on (Dyrektor Generalny KOWR, 2019)*

Voivodeship	Population density [people/km^2]	Number of agri-gas plants	As of 26.06.2020
Dolnośląskie	146	10	10
Kujawsko-Pomorskie	116	6	7
Lubelskie	85	7	7
Lubuskie	73	4	4
Łódzkie	137	4	4
Małopolskie	222	2	2
Mazowieckie	150	6	6
Opolskie	106	1	1
Podkarpackie	119	3	3
Podlaskie	59	9	10
Pomorskie	126	9	11
Śląskie	371	2	2
Świętokrzyskie	107	1	1
Warmińsko-Mazurskie	60	10	12
Wielkopolskie	117	11	12
Zachodniopomorskie	75	13	13
Poland	123	–	–

As can be seen in Table 1 posted on page 22, Zachodniopomorskie voivodeship retained its leading position with 13 agricultural biogas plants. The next positions were taken by Wielkopolskie and Warmińsko-Mazurskie voivodeships, which had 12 biogas plants each, followed by Pomorskie Voivodeship (11) and Dolnośląskie and Podlaskie voivodeships (10 each). In turn, Opole and Świętokrzyskie voivodeships had one agricultural biogas plant each, and Śląskie voivodeship had only two.

Analyzing the distribution of the agricultural biogas plants, it can be concluded that most of them were in voivodeships with population densities that were lower than the national average of 123 people per square kilometer; these were the following voivodeships: Warmińsko-Mazurskie (60), Zachodniopomorskie (75), Podlaskie (59), and Wielkopolskie (11). The existence of a large number of biogas plants in Dolnośląskie, Pomorskie, and Mazowieckie voivodeships can be explained by the existence of several large urban centers, while the populations were lower in the rural and urban-rural communes. This is illustrated by the data in Table 2, which shows that, as of March 5, 2019, 50.5% of the Polish agri-gas plants were located in communes with population densities of less than 50 people per square kilometer. The percentage as of June 2, 2020, this share increased to 53.3%. During the period that was analyzed, the number of agri-gas plants that were located in communes with population densities within a range of 25.1–50 people per square kilometer increased the most (by six percentage points).

Table 2. *Number of agri-gas plants vs. population density in communes – own study based on (Dyrektor Generalny KOWR, 2019)*

Population density [people/km^2]	**Number of agri-gas plants**	**As of 26.06.2020**
< 25.0	12	13
25.1–50.0	37	43
50.1–75.0	19	18
75.0–100.0	13	15
100.1–125.0	6	5
125.1–150.0	4	4
> 150.1	6	7
Overall	97	105

The numbers of new agricultural biogas producers that were registered during the years of 2011–2020 are presented in Table 3. The highest numbers (21 each) were in 2015 and 2016, while the lowest were in 2018. The collapse of the growth trend after 2016 cannot be associated with the profitability of the operations of agri-gas plants, as *blue certificates* had been in force for the energy that is produced in agricultural biogas plants since 2016 – the price of which being 150 to 200% greater than the prices of the *green certificates* for the other renewable energy sources (Iwaszczuk et al., 2019).

Table 3. *Number of registered agri-gas plants for period of 2011–2020 – own study based on (Dyrektor Generalny KOWR, 2019)*

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020[a]
Number	14	10	13	16	21	21	3	1	7	5

[a] through 26.06.2020

4. FACTORS THAT INFLUENCE LOCATIONS OF AGRICULTURAL BIOGAS PLANTS IN POLAND

Large resources of the substrates that are produced by the Polish agri-food sector are used to a small extent for the production of agricultural biogas, which is associated with the threats that are related to the operation of agri-gas plants. As recently as 2015, Igliński and his colleagues conducted a SWOT analysis; as a result of this, they identified the most important threats as follows (Igliński et al., 2015):

- instability of prices of agricultural substrates,
- no guarantee of stable input supplies,
- decrease in prices of conventional fuels.

The SWOT analysis that was conducted by Iwaszczuk et al. (2019) listed the following threats:

- price drop of blue certificates,
- instability of prices of substrates from crops for energy purposes,
- decrease in prices for disposal of agri-food waste,
- decrease in prices of conventional fuels,
- increase in land and real estate taxes,
- closure of large agri-food processing plant that supplied substrates to biogas plant,
- epidemic among animals, causing destruction of entire herds,
- recurring natural disasters.

The weaknesses in both analyses included the resistance of the local community and the long investment process, which can be associated with both this resistance and the lack of local spatial-development plans in most commune areas.

In order to explain the reasons for the small number of biogas plants in Poland, Igliński et al. (2020) used a PEST analysis, which takes macroenvironmental factors into account: political (P), economic (E), social (S), and technological (T). The analysis showed that the greatest threats to the development of agricultural biogas plants were the strong conventional energy lobby, an unfriendly energy policy, an uncertain global economic situation, the low possibilities of financing biogas investments from investors' own funds, the low social acceptance of biogas technology, the poor condition of the power grid in Poland, and the poor cooperation between industry and science.

After analyzing the literature on the issue of agricultural biogas production, the statistical data, and interviews in those towns where agri-gas plants operated (Piekoszów, Liszkowo), the authors decided to investigate the factors that supported the construction of agricultural biogas plants. Such factors were considered to be as follows:

- knowledge about process, which affects safety and eliminates operational nuisances (W),
- availability of substrates (price, transport costs, regularity of deliveries) (S),

- price of energy from renewable energy sources, ensuring economic profitability of operation (C),
- costs of agri-food waste disposal and possibility of other uses (U),
- population density in commune (G),
- spatial order in commune that resulted from local development plan or historically shaped residential development (P).

5. FACTORS

During the analysis, the following $n = 6$ factors were taken into account:

1) knowledge (W), understood in context of nuisance to environment,
2) substrates (S) – waste or corn cultivation,
3) energy price (C), including certificates for electricity and heat,
4) cost of waste disposal (U), related to possibility of using it for purposes other than biogas production,
5) population density in commune (G),
6) adopted local development plan in commune (P) – urban order related to local history.

6. DIRECT INFLUENCE OF FACTORS

During the analysis of the influence of the factors, original DEMATEL version was used; this allowed us to express the strength of the direct influence of one of the compared factors on another factor using the following scale:

0. no direct influence of first of pair of compared factors on second,
1. little influence of first factor,
2. high influence,
3. very high influence,
4. extreme influence.

The set of n^2 estimates of the direct impact of the factors expresses the structure of their direct impact. It is worth noting that, when determining the structure of direct influence:

- we take the possibility of both directions of the interactions that occur between the i-th and j-th factors into account $(i, j = 1 \dots n)$;
- it is not possible for an individual factor to have a direct influence on itself.

In the case of the set of factors { W, S, C, U, G, P }, the assumed structure of the direct influence is illustrated by a directed graph – *direct influence graph* (presented in Figure 1). The lack of a direct influence of the factors corresponds to the lack of an arc that connects the vertices of the factors. However, the direct influence at the level of the individual scale degrees is expressed by different types of arc lines:

- dotted line corresponds to direct impact assessment of Level 1,
- dash line – Level 2,
- thin solid line – Level 3,
- bold solid line – Level 4.

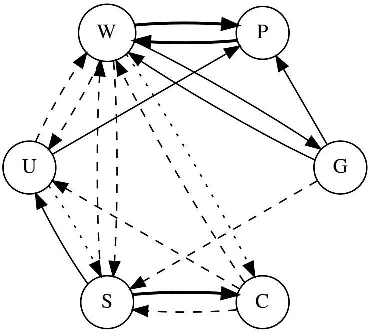

Fig. 1. *Assumed structure of direct influence of factors*

Note that the image of the structure of the direct influence may also suggest the hierarchical nature of the structure of direct influence – as, e.g., in Figure 2.

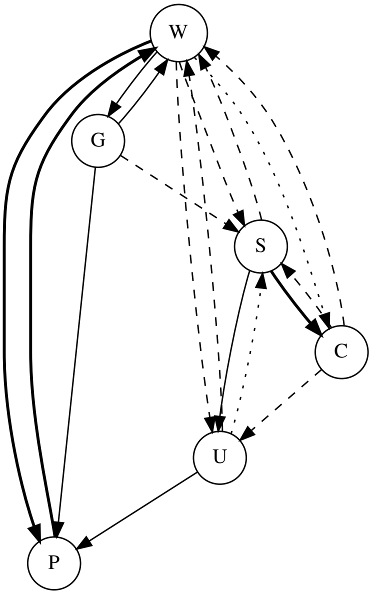

Fig. 2. *Suggested hierarchy of direct influence factors structure*

The structure of the direct influence is also expressed in a dedicated square *matrix of direct influence* X^* with n rows and n columns that correspond to the subsequent factors. In the case under consideration, assume that the order of factors W, S, C, U, G, and P takes the following form:

$$X^* = \begin{bmatrix} 0 & 2 & 1 & 2 & 3 & 4 \\ 2 & 0 & 4 & 3 & 0 & 0 \\ 2 & 2 & 0 & 2 & 0 & 0 \\ 2 & 1 & 0 & 0 & 0 & 3 \\ 3 & 2 & 0 & 0 & 0 & 3 \\ 4 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{1}$$

As a result of dividing it by the maximum row sum of its elements (which is $\lambda = 12$), we obtain its normalized form:

$$X = \frac{X^*}{\lambda}, \tag{2}$$

which should meet the following condition:

$$\lim_{k \to \infty} X^k = 0. \tag{3}$$

Based on this, we finally obtain the *total influence structure*, expressed by *total influence matrix* T:

$$T = X\,(I - X)^{-1}. \tag{4}$$

It is worth noting that the total impact can also be expressed as the sum of the impact:

- direct X (2);
- indirect impact resulting from transmission, which – thanks to Property 3 – can be estimated using following formula:

$$\varDelta X = X^2\,(I - X)^{-1}. \tag{5}$$

Thus:

$$T = X + \varDelta X. \tag{6}$$

By applying both Formulas (4) and (6), we finally obtain the following form of the total impact structure:

$$T = \begin{bmatrix} 0.4938 & 0.3857 & 0.2530 & 0.3876 & 0.3735 & 0.6882 \\ 0.4854 & 0.2135 & 0.4449 & 0.4584 & 0.1213 & 0.3067 \\ 0.3989 & 0.2995 & 0.1331 & 0.3302 & 0.0997 & 0.2404 \\ 0.4139 & 0.1975 & 0.1003 & 0.1351 & 0.1035 & 0.4476 \\ 0.5788 & 0.3308 & 0.1585 & 0.2056 & 0.1447 & 0.5305 \\ 0.4979 & 0.1286 & 0.0843 & 0.1292 & 0.1245 & 0.2294 \end{bmatrix}, \tag{7}$$

where:

$$\varDelta X = \begin{bmatrix} 0.4938 & 0.2190 & 0.1697 & 0.2209 & 0.1235 & 0.3549 \\ 0.3187 & 0.2135 & 0.1116 & 0.2084 & 0.1213 & 0.3067 \\ 0.2322 & 0.1328 & 0.1331 & 0.1635 & 0.0997 & 0.2404 \\ 0.2472 & 0.1142 & 0.1003 & 0.1351 & 0.1035 & 0.1976 \\ 0.3288 & 0.1641 & 0.1585 & 0.2056 & 0.1447 & 0.2805 \\ 0.1646 & 0.1286 & 0.0843 & 0.1292 & 0.1245 & 0.2294 \end{bmatrix}. \tag{8}$$

Based on the obtained structure of the total influence T (Formula (7)), a pair of indicators can be obtained for each of the factors:

$$\begin{aligned} \forall_{i=1\ldots n}\ s_i^+ &= \sum_j^n t_{ij} + t_{ji}, \\ \forall_{i=1\ldots n}\ s_i^- &= \sum_j^n t_{ij} - t_{ji}, \end{aligned} \tag{9}$$

which are called indicators, respectively: position or prominence (en.*prominence*) s_i^+ and relation (en. *relation*) s_i^-. The first expresses the strength of the connections of the i-th factor with the factors[1]. The second one allows us to express the character – causal ($s_i^- > 0$), consequential ($s_i^- < 0$), or neutral ($s_i^- = 0$) – the i-th next factor. Therefore, the relationship and position indicators help in the two-dimensional classification of the factors, which are carried out according to their nature and the strength of the connections between them. The results of such a classification are illustrated in Table 4.

Table 4. *Two-dimensional factor classification*

Factor: i	**W** 1	**S** 2	**C** 3	**U** 4	**G** 5	**P** 6
s_i^+	5,450	3,585	2,675	3,044	2,916	3,636
s_i^-	–0.287	+0.474	+0.327	–0.248	+0.981	–1.249
Connections	Strong	Medium	Weak	Weak	Weak	Medium
Nature	Effect	Cause	Cause	Effect	Cause	Effect
Quarter	IV	II	II	III	II	III

Note that the term *quadrants* refers to the quadrants of the $s^+ - s^-$ coordinate system, created by shifting the ordinate axes s^- to point $s^+ = 4.063$, located on the abscissa of s^+, in the middle of the interval between the upper ($s_1^+ = 5.450$) and lower ($s^+ = 2.675$) limit prominence index (compare: Figure 3).

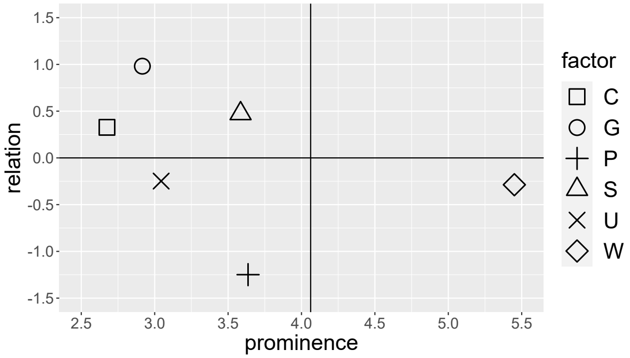

Fig. 3. *Graphical illustration of factor classification results*

---

[1] Due to the possible indirect influence of the other factors – also with themselves!

Based on the content of Table 4 it can be concluded that:

1) The factor with the most clear causal character is factor G, which is rather a weakly related factor. Factor C is also similar in nature. The list of causes is exhausted by factor S, which distinguishes it from the rest of the causes with rather average connections.
2) The most visible effect is the P factor, which stands out from the rest of the effects due to its rather average level of connections (the U factor has weak connections and the W factor has strong connections).

The analysis shows that the key factors for the development of biogas plants in Poland include population density G, energy price C and availability of substrates S.

7. DISCUSSION OF THE RESULTS OF THE ANALYSIS USING THE PEST AND DEMATEL METHODS

In the PEST method, Igliński et al. (2020) presented the examined factors on a point scale in which a highly unfavorable factor was assigned a value of 1 and a very favorable factor a value of 5. Based on the data that was obtained in our surveys, it was assumed that, in the areas of the political, social, and technical environments, a very favorable factor (value 5.0) was Poland's membership in the EU. The same value in the area of economic environment was adopted for globalization, as it ensures the free flow of goods, capital, and services. Only the conventional energy lobby in the political environment was considered to be a highly unfavorable factor (value 1). Unfavorable factors (value 2) were assumed for the renewable energy policy in the area of the political environment and the ability of science and economy to cooperate in the area of the technical environment. The average value of the selected factors was calculated for each environment. When assessing the environment, it was assumed that the environment was highly unfavorable if the mean was less than 2.0; unfavorable when it was within a range of 2.00–2.99; neutral (range 3.00–3.49); favorable for a mean within a range of 3.50–4.49, and very favorable for a mean greater than 4.50. The following average values were obtained for the individual areas:

- political environment: 3.25,
- economic environment: 3.88,
- social environment: 3.56,
- technical environment: 3.25.

The values that are presented above show that the reason for the slow development of agricultural biogas plants is the lack of areas with very favorable conditions. Only the economic environment can be considered to be favorable, while the rest are neutral.

The analysis using the DEMATEL method showed that the key factors for the locations of agricultural biogas plants were population density, energy prices, and the availability of substrates.

8. CONCLUSIONS

The development of biogas plants in Poland should be based on modern management, which would use modern decision-support methods. The article presents the practical application of the DEMATEL method, which was used to determine the matrix of the mutual connections between the influences of each pair of the factors (knowledge, substrates, energy price, cost of waste disposal, population density, and the adopted local development plan in the commune). A total influence matrix T was constructed, and a pair of indicators (called the position and relationship indicators) were obtained for each factor. The factors that had the greatest and least influence on the development of biogas plants in Poland were determined.

As a result of the analysis that was carried out regarding the development of the biogas plant market in Poland, the most important factors included the following:

- Population density G – this result was not accidental, as the operation of an agricultural biogas plant has a strong impact on the people who live in its vicinity; this mainly concerns the odors that are released from substrate storage containers in a biogas plant and the odors that are released from the anaerobic fermentation chambers.
- Price of energy C – this depends on the price of "blue certificates," which were introduced in Poland in 2016; the incentive for investors was the higher price of "blue certificates" as compared to "green" certificates. Setting the price at a higher level was intended to compensate for the high costs of investing in agri-gas plants.
- Availability of S substrates – the production and quality of agricultural biogas depends on the type of substrate that is used in the fermentation process; most often, biogas is produced from farm animal excrement and corn stalks. Another source of substrates may be agri-food and slaughterhouse waste – the use of which allows for the production of very good quality biogas, which is characterized by a high methane content. After compression, such a biogas can be used to power automobile engines.

REFERENCES

Dyrektor Generalny KOWR (2019). *Wytwórcy biogazu rolniczego.* https://www.kowr.gov.pl/odnawialne-zrodla-energii/biogaz-rolniczy/wytworcy-biogazu-rolniczego.html [2.06.2019].

Gradziuk P. (2017). Potencjał i prognozy wykorzystania biogazu rolniczego w Polsce. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, **19**, pp. 64–70. DOI: 10.22004/ag.econ.293541.

Igliński B., Buczkowski R. & Cichosz M. (2015). Biogazownie rolnicze w Polsce – stan aktualny, potencjał, analiza SWOT. *Rynek Energii*, **118**(3), pp. 93–101.

Igliński B., Piechota G., Iwański P., Skarzatek M. & Pilarski G. (2020). 15 years of the Polish agricultural biogas plants: their history, current status, biogas potential and perspectives. *Clean Technologies and Environmental Policy*, **22**, pp. 281–307. DOI: 10.1007/s10098-020-01812-3.

Iwaszczuk N., Szyba M., Iwaszczuk A. & Yakubiv V. (2019). Production of agricultural biogas from waste – an element of socially responsible actions in the food sector. *Acta Innovations*, **33**, pp. 52–62. DOI: 10.32933/ActaInnovations.33.5.

Kowalczyk-Juśko A. (2014). Wykorzystanie masy pofermentacyjnej – krok po kroku. *Czysta Energia*, **3**, pp. 38–40.

Lyng K.-A., Skovsgaard L., Jacobsen H. & Hanssen O. (2020). The implications of economic instruments on biogas value chains: A case study comparison between Norway and Denmark. *Environment, Development and Sustainability*, **22**, pp. 7125–7152. DOI: 10.1007/s10668-019-00463-9.

Majoch A. & Jabłońska M. (2013). Bioodpady jako nowe źródło energii odnawialnej. *Nafta i Gaz*, **9**, pp. 673–682.

Ministerstwo Energetyki RP (2019). *Polityka energetyczna Polski do 2040 r.* https://www.gov.pl/web/klimat/polityka-energetyczna-polski [7.09.2023].

Podkówka W. (Ed.). (2012). *Biogaz rolniczy odnawialne źródło energii – teoria i praktyczne zastosowanie*. Powszechne Wydawnictwo Rolnicze i Leśne, Warszawa.

Rada Ministrów RP (2010). *Kierunki rozwoju biogazowni rolniczych w Polsce w latach 2010–2020.* https://www.premier.gov.pl/wydarzenia/decyzje_rzadu/kierunki-rozwoju-biogazowni-rolniczych-w-polsce-w-latach-2010-2020.html [5.03.2019].