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Biogas production from the perspective of sustainable development

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Abstract: One of the basic aspects of sustainable development strategy involves investments in green technologies, including energy production from renewable sources. Biomass, special organic waste which belongs to "green sources" of energy can be used in the methane fermentation process of biogas production to generate heat and electricity.
Biogas power plants have functioned in the Polish energy industry for many years now. On the basis of the data available from Central Statistical Office, in 2014 the ratio of biogas accounted for 7.6% of the structure of primary energy derived from renewable sources in the EU and 2.6% in Poland. An important consideration related to the production of biogas is associated with the applicability of waste resources derived from agricultural production and from the food industry, including pig slurry, slaughterhouse waste, brewing and distilling dregs as well as others. The operation of biogas plants provides considerable benefits to the environment, resulting from the controlled fermentation process and its application in the production of useful energy, as it can provide reduction of the emission of methane and other greenhouse gases. The aspects including the reduction of the volume of waste, environmental protection, fulfillment of the EU obligations and local energy security, form the reasons why communes in Poland should focus their attention on the use of biogas.
This paper presents the results of SWOT analysis of biogas production in the context of sustainable development. The assessment of the aspects (strengths, weaknesses, opportunities and threats) and the intensity of their impact were undertaken on the basis of a point scale developed by the authors. The analysis shows that the process demonstrates a number of strengths, which can promote the implementation of positive changes in the environmental and social aspects undertaken on a local scale.

Keywords: biogas production, sustainable development

JEL codes: Q01, Q20, Q40, R11

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1. Introduction

The concept of sustainable development involves the need to meet basic necessities of human communities and extends to the opportunity to satisfy aspirations with regard to development, without compromising needs of the future generations (Szczakowski, 2003; Toruński, 2010).

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This definition involves both the aspects of economic and social development, as they should not be implemented at the expense of an excessive utilization of non-renewable resources and degradation of the natural environment. Sustainable development is determined by ecological space and involvement of various economic, environmental or social aspects. The legal status of the concept of sustainable development was defined in the Polish law in 1997, when it appeared in the Act on Environmental Protection and Forming of the Environment and in the Constitution of the Republic of Poland (Macnaghten, Urry, 2005; Toruński, 2010). In addition, the definition can also be found in the Act of 27 April 2001 - Environmental Protection Law, where the following statement with regard to sustainable development is given: "sustainable development means social and economic development which integrates political, economic and social activities while maintaining natural balance and permanence of basic natural processes in order to guarantee the possibility of satisfying basic needs of particular communities or citizens of the existing generation and the generations to come" (consolidated text, Journal of Laws No. 62, 2001, item 627).

The demand for energy increases year after year, and the use of renewable sources is gaining in popularity. The use of biomass, wind, solar or water energy can provide significant economic benefits and form a guarantee of energy generation while the impact of this production on the environment can be followed and mitigated – therefore such sources play an increasingly important role in the domestic energy policy (Akbas et al., 2015). Today, the list of the few available environmentally friendly ways of energy production includes the production of biogas in fermenters, as well as in the process of anaerobic digestion, and by application of various types of waste, among others sewage sludge (Agrafioti et al., 2013; Zielińska et al., 2015; Stefaniuk, Oleszczuk, 2015), animal manure (Cao, Harris, 2010; Stefaniuk, Oleszczuk, 2015), as well as using waste derived from food and agricultural waste (Inyang et al., 2010; Sun et al., 2013; Stefaniuk, Oleszczuk, 2015) as well as from industry (e.g. obtained during food processing, and in dairy, sugar, pharmaceutical, cosmetics, biochemical, paper and meat industries), etc.

A variety of cattle, pig and poultry manure can be used as a substrate in the production of agricultural biogas. Organic substances have various decomposition rate and different amounts of biogas are derived from them in the methane fermentation process. The fermentation process in which a variety of different substances are added and mixed is called co-fermentation. The range of waste with a potential application for the biogas production process is very extensive

(Miah et al., 2016; Curkowski, Oniszk-Popławska, 2010). Substrates are used in various forms, volume ratios and at different temperatures during biogas production in a biogas plant. In addition, there are biogas installations, which apply different fractions separated from each other, including solid and liquid forms (Möller, Müller, 2012; Stefaniuk, Oleszczuk, 2015).

One of the common methods applied in the evaluation of new undertakings involves the use of SWOT analysis. This analysis is often used in various sectors, including renewable energy (Budzianowski, Chasiak, 2011; Budzianowski, 2012; Chen et al., 2014; Igliński et al., 2015). This type of analysis provides a multi-faceted assessment of the activities and has proved to be an effective tool and has constituted a suitable baseline to diagnose current problems and to sketch future action plans. This procedure has local, national and international dimensions. SWOT analysis is applied among others by businesses, public institution and non-profit organizations (Tylińska, 2005; Nazarko, Kędzior, 2010).

The objective of this paper is to report on the results of a study focusing on the assessment of strengths and weaknesses as well as opportunities and threats associated with biogas production from biomass. The study into biogas production process was undertaken from the perspective of sustainable development and applied SWOT analysis, which accounted for both the external factors of this process forming the sources of the strengths and weaknesses of an investment as well as opportunities and threats that are related to the environment in which the process is realized.

2. Biogas production from biomass – SWOT analysis

The production of biogas from waste is a project that has its advocates, yet, it also attracts a variety of opposite opinions. The task embarked on in this paper is to evaluate this production by application of SWOT procedure, taking into account four strategic factors, namely: strengths, weaknesses, and opportunities and threats associated with the process.

The adopted methodology employed the assessment of the strategic factors on the basis of a point scale, and an evaluation of biogas production process in terms of criteria related to sustainable development, taking into account the environmental, economic and social aspects. The scope of the SWOT analysis was extended to cover the assessment of the intensity of impacts on the environment and society by means of the adopted three-point scale.

In the SWOT analysis the evaluation of the strategic factors and strengths, weaknesses, and opportunities and threats associated with the biogas production applied a point scale and weights were adapted from the publication Koziar (2017), but weights were evaluated by subjective opinion of authors. In this analysis, the score “-2” points means that the factor is considered a considerable weakness; “-1” point denotes a weakness; “+1” point denotes a factor that forms a strength; “+2” points denotes a considerable strength. The evaluation of a factor to be either an opportunity or a threat applies the following point scale, where “-2” points means a considerable threat; “-1” point denotes a threat with a smaller impact; “0” points – a factor that cannot be classified clearly as either a threat or an opportunity; “+1” point denotes a factor considered an opportunity; “+2” points means that the factor forms an opportunity with a considerable impact. Each of the identified strengths and weaknesses as well as opportunities and threats is given an adequate weight, where “3” means the highest weight; “2” average weight, whereas “1” denotes a low weight. The final score is expressed as a product of the evaluation of a given factor and its weight. The greater the result gained from the overall evaluation (both positive and negative), the more important the factor can be considered in comparison with the other ones. The calculation of the final assessment of the strategic factors (strengths, weaknesses, opportunities and threats) associated with biogas production from biomass applied the following relation:

$$F = FR \cdot W \tag{1}$$

where: F- final score (strengths/weaknesses or opportunities/threats of the biogas production process), FR - factor assessment (strengths/weaknesses or opportunities/threats), W – weight.

The results of the overall assessment of the strengths and weaknesses associated with biogas production are summarized in Table 1, whereas Table 2 contains details of the opportunities and threats associated with the process.

Table 1. Strengths and weaknesses associated with biogas production from biomass

No.	Strengths and weaknesses associated with biogas production	Evaluation of a factor as		Weight (1-3)	Final score
		weakness	strength		
1.	Local accessibility of waste derived from various sources		+2	3	+6
2.	Potential for application of various types of waste, considerable potential of organic waste		+2	3	+6

3.	A wide range of applicability of generated biogas (e.g. in the electricity and heat production, etc.)		+2	3	+6

Table 1 (continued)

No.	Strengths and weaknesses associated with biogas production	Evaluation of a factor as		Weight (1-3)	Final score
		weakness	strength		
4.	Potential agricultural use of digestate – as a marketable product		+2	2	+4
5.	Free-of-charge access to waste produced by businesses and farms (cheap substrate)		+2	2	+4
6.	Financial stability of businesses in agricultural and food industries		+1	2	+2
7.	Interest in energy production from RES, growing interest in innovations and new technologies		+1	3	+3
8.	Existence of modern and active research centres and R&D units		+1	3	+3
9.	Potential for local utilization of produced energy		+2	3	+6
10.	Creation of new workplaces		+2	3	+6
11.	Considerable geographical scatter of waste producers	-1		2	-2
12.	Demand for considerable capital for investment.	-2		3	-6
13.	Protests of coal community against existence of biogas plants in vicinity of their households and in the surrounding area	-2		3	-6
14.	Problems with access to power supply	-2		2	-4

Source: Author's own elaboration.

On the basis of the overall evaluation of strengths and weaknesses (Table 1), we can find that the most important strength of this process (“+6”) is associated with the local availability of waste and potential for application of various types of waste for the purposes of the production of electricity and heat for the demand of the local community. In addition, an important role is attributed to the aspect of creating new workplaces, which is likely to decrease the local unemployment. The principal weakness of this process (“-6”) is associated with the need to provide considerable funding for the purposes of the investment as well as the possibility of the protests on the part of a local community. These drawbacks can be dealt with as a result of extensive education, dialog and meetings with the local community.

Table 2. Opportunities and threats associated with the biogas production process derived from waste biomass

No.	Opportunities and threats associated with the biogas production process derived	Assessment of environmental impact	Weight (1-3)	Final score
1.	Difficulties in handling of administrative formalities, legal restrictions	-2	2	-4
2.	High cost of investment	-2	3	-6
3.	Protests of the local community	-2	3	-6
4.	Problems in dealing with authorities, legal restrictions	-1	2	-2
5.	Lack of a stable prospect of gaining support for business and investment	-1	2	-2
6.	Implementation of new solutions and technologies in the market	+1	2	+2
7.	Utilization of putrescible waste in agricultural areas	+1	2	+2
8.	Improvement of environmental conditions in local plant production and horticulture by replacing mineral fertilizers by natural fertilizers generated from biogas (ecological fertilizer)	+2	3	+6
9.	Protection of environment and climate	+2	3	+6
10.	Decrease of amount of landfilled waste	+2	3	+6
11.	Common application of biomass (e.g. derived from waste) in the production of energy from biogas	+2	3	+6
12.	Decrease in the use of non-renewable resources in energy production – coal, oil and natural gas	+2	3	+6
13.	Effective manner to limit methane emission from agricultural production	+1	3	+3
14.	Creation of local approval for investments in renewable energy, decrease in the amount of landfilled waste and improvement of management in the energy sector and use of natural resources	+1	3	+3
15.	Biogas production based on biochemical processes. No necessity to apply chemical agents forming hazard to environment	+1	2	+2
16.	Fermenting chambers tightly sealed, which prevents odors from escaping into environment	+1	2	+2
17.	Application of energy generated from biogas for internal local demand (energy self-sufficiency)	+2	3	+6
18.	Better accessibility to various forms of financial support– funding from both domestic and EU sources	+1	2	+2
19.	Investment in building a biogas plant has a short pay-back period, which brings considerable economic benefits and profit	+1	2	+2
20.	Overall increase in the ecological awareness in the fields of ecological technologies and waste utilization	+1	1	+1
21.	Development of human capital in an enterprise – new competences and skills: technical, logistics, finance	+1	1	+1
22.	Development of social capital – ability to extend the existing network of cooperation, confidence and long-term combined effort	+1	1	+1

23.	Integration of local communities and all stakeholders (local authorities, businesses, non-governmental organizations, youth and children, media, etc.)	+1	1	+1
24.	Energy derived from a biogas plant forming a source of additional income and leading to an increase in the local agricultural production	+2	2	+4

Source: Author's own elaboration.

The process of biogas production leads to the development of significant opportunities, including: using waste materials and biomass and generated energy from biogas for the internal load of the plant (energy self-sufficiency), improving the quality of environmental conditions (protection of the environment and climate), reduction of the use of non-renewable resources applied in energy production and reduction of the amount of landfilled waste. The overall assessment of the strategic factors associated with opportunities and threats clearly demonstrates that the biogas production process creates more opportunities for a favorable change compared with the threats that can pose a future hazard.

The summary of the SWOT analysis undertaken with regard to biogas production in the aspect of sustainability criteria is presented in Table 3. It illustrates the impact of biogas production on the environment, economic factors and society.

Table 3. Evaluation of biogas production in terms of sustainable development criteria

Biogas production from waste biomass		**Environmental aspect**	**Economic aspect**	**Social aspect**
Strengths (S)	Local accessibility of waste derived from various sources	X	X	X
	Potential for application of various types of waste, considerable potential of organic waste	X	X	X
	A wide range of applicability of generated biogas (e.g. in the electricity and heat production, etc.)	X	X	X
	Potential agricultural use of digestate – as a marketable product	X	X	X
	Free-of-charge access to waste produced by businesses and farms (cheap substrate)		X	

Table 3 (continued)

	Biogas production from waste biomass	Environmental aspect	Economic aspect	Social aspect
Strengths (S)	Financial stability of businesses in agricultural and food industries		X	
	Interest in energy production from RES, growing interest in innovations and new technologies			X
	Existence of modern and active research centers and R&D units			X
	Potential for local utilization of produced energy			X
	Creation of new workplaces			X
Weaknesses (W)	Considerable geographical scatter of waste producers		X	
	Demand for considerable capital for investment		X	
	Protests of coal community against existence of biogas plants in vicinity of their households and in the surrounding area			X
	Problems with access to power supply			X
Threats (T)	Difficulties in handling administrative formalities, legal restrictions	X	X	X
	High cost of investment		X	
	Protests of the local community			X
	Lack of a stable perspective of gaining support for undertakings and investments		X	
Opportunities (O)	Implementation of new solutions and technologies in the market	X	X	X
	Utilization of putrescible waste in agricultural areas	X		
	Application of waste resources, limitation of landfill waste resulting from its application in biogas technologies	X	X	X
	Improvement of environmental conditions in local plant production and horticulture by replacing mineral fertilizers by natural fertilizers generated from biogas (ecological fertilizer)	X	X	
	Protection of environment and climate	X		X
	Decrease in the amount of landfilled waste	X		X
	Common application of biomass (e.g. derived from waste) in the production of energy from biogas	X	X	
	Decrease in the use of non-renewable resources in energy production – coal, oil and natural gas	X		
	Effective manner to limit methane emission from agricultural production	X		
	Creation of local approval for investments in renewable energy, decrease in the amount of landfilled waste and improvement of management in the energy sector and use of natural resources	X		X
	Biogas production based on biochemical processes. No necessity to apply chemical agents forming hazard to environment	X		
	Fermenting chambers tightly sealed, which prevents odors from escaping into environment	X		X
	Application of energy generated from biogas for internal local demand (energy self-sufficiency)	X		X

Table 3 (continued)

	Biogas production from waste biomass	Environmental aspect	Economic aspect	Social aspect
Opportunities (O)	Better accessibility to various forms of financial support– funding from both domestic and EU sources		X	
	Investment in building a biogas plant has a short pay-back period, which brings considerable economic benefits and profit		X	X
	Overall increase in the ecological awareness in the fields of ecological technologies and waste utilization			X
	Development of human capital in an enterprise – new competence and skills: technical, logistics, finance			X
	Development of social capital – ability to extend the existing network of cooperation, confidence and long-term combined effort			X
	Integration of local communities and all stakeholders (local authorities, businesses, non-governmental organizations, youth and children, media, etc.)			X
	Energy derived from a biogas plant forming a source of additional income and leading to an increase in the local agricultural production			X

Source: Author's own elaboration.

The biogas production process offers a number of environmental and social benefits, including the improvement of the quality of the environment for the purposes of the local crop production and horticulture by replacing fertilizers with digestate derived from the fermentation process. Biogas production offers a considerable opportunity for small rural communities and can contribute to numerous changes, including an increase in agricultural production. The general improvement of the environmental quality brings an improvement of the economic well-being, since some of the expenses can be limited as a result of improved environmental condition, among others this includes health care (e.g. as a result of a decrease in pollution-related diseases, sick leave), losses related to deficits in agricultural or forestry production, etc. The production of energy derived from biogas can form an attractive solution in the geographical areas where connection to a traditional power grid is unfeasible or difficult as well as contribute to the development of the local community and increase locally generated revenues.

In addition, the potential for development creates access to various forms of support – gaining co-finance from various resources, both domestic and the EU. The analysis of the biogas production process (Table 3) demonstrates that the production of biogas from biomass leads to progress in the development of local communities (as a result of an increase in ecological awareness and economic gains associated with the biogas production process, acquisition of new competences and skills, etc.). It also offers a measure to stimulate the conservation of the natural environment for future generations. Despite many positive aspects of the biogas production process, there is a high risk resulting from the fluctuating energy and economic market conditions as well as from burdensome and long-lasting procedures needed to obtain documentation required for this type of activity.

With the purpose of extending the scope of the SWOT analysis, the assessment of the effect was also conducted by application of a three-point scale developed by Kaszubska, Wzorek (2017: 347-361). The intensity of the impact was measured on a scale from 0 to 3 (0-no impact, 1-little impact, 2-average impact, 3-considerable impact). Table 4 contains a list with examples of impacts having a potential effect on the natural environment and the local community inhabiting the rural area. This work also contains a conclusion that the investment in the biogas production derived from biomass forms an opportunity for the development of rural areas.

Table 4. Examples of factors with an effect on environment and local community

	Type of impact	Impact: positive (P) /negatyve (N)	Intensity of impact on:	
			environment	community
Environmental aspect	Potential for application of various types of waste, considerable potential of organic waste	P	3	3
	Difficulties in handling of administrative formalities, legal restrictions	N	1	3
	A wide range of applicability of generated biogas (e.g. in the electricity and heat production, etc.)	P	2	2
	Potential agricultural use of digestate – as a marketable product	P	3	3
	Limitation of landfill waste resulting from its application in biogas technologies	P	3	3
	Common application of biomass (e.g. derived from waste) in the–production of energy from biogas	P	3	3
	Replacing mineral fertilizers by natural fertilizers generated from biogas (ecological fertilizer)	P	2	2

Table 4 (continued)

	Type of impact	**Impact: positive (P) /negatyve (N)**	**Intensity of impact on:**	
			environment	**community**
Social aspect	Potential for local utilization of produced energy	P	2	3
	New workplaces	P	1	3
	Protests of the local community	N	0	3
	Social acceptance of investments in energy from renewable sources	P	0	2
	Tightness of fermentation chamber throughout the production process – lack of odors	P	2	2
	Energy self-sufficiency of a farm	P	1	3
Economic aspect	Cheap substrate	P	2	3
	Considerable geographical scatter of waste producers	N	2	2
	Demand for considerable capital for an investment	N	1	3
	Possibility to secure funding from various resources – domestic and the EU	P	0	3
	Investment in building a biogas plant having a short pay-back period	P	1	3
	High cost of investment	N	0	3
	Summary	**N=5, P=14**	**29**	**52**

Source: Author's own elaboration.

The majority of the factors taken into account in the study were found to play a positive role. The number of positive factors is greater compared to negative ones by a total of nine. Positive impacts (P) are mainly ones with an average (35.71%) and considerable (28.57%) impact on the environment and with a considerable (71.43%) and average (28.57%) impact on the community. In contrast, negative impacts (N) are mainly impacts with a low impact (40%) on the environment and a considerable impact (80%) on the community. The economic aspect of sustainable development has the highest number of negative impacts compared with the environmental and social aspects. The analysis (Table 4) also shows that the intensity of the impact of factors related to the biogas production process on society is greater (over 1.7 times) than the impact on the natural environment.

Despite the environmental and socio-economic benefits, there are certain obstacles to the production of biogas. The biogas production process is affected by a variety of stimuli and barriers (Lantz et al., 2007). The technologies of renewable energy production face a number of obstacles including, among others: technical, market, economic and financial barriers, institutional, political and regulatory barriers, as well as social and environmental obstacles (Painuly, 2001). These barriers were found to vary completely, depending on the geographical location. For example, in Romania, the production and use of biogas is uncommon due to the market barriers, lack of knowledge and experience (farmers, installation operators, etc.) and insufficient access to sources of finance (Mateescu et al., 2008). In Rwanda, however, the main obstacles to biogas installations include financial, technical, socio-cultural and institutional barriers. The most important challenges are potential biogas users who cannot afford high installation costs, and loans from banks are difficult to obtain (Rupf et al., 2015). In Poland, there are many barriers to the investment process and access to the sources of funding. The obstacle is also associated with legal regulations, social barriers (little acceptance of biogas plants by local residents), mainly resulting from the deficiencies in the education regarding biogas production in a biogas plant. (Igliński et al., 2012; McCormick, Kåberger, 2007).

5. Conclusions

Every year, the level of knowledge and awareness regarding the application of waste biomass in energy production increases, including energy generation from RES. This paper contains a report on the results of a SWOT analysis performed with regard to biogas production process from biomass, accounting for the environmental, social and economic aspects of sustainable development. The obtained SWOT analysis results may be useful in practice and the weights use in the SWOT analysis can be applied in different situations/countries for the evaluation of given factors. The SWOT analysis demonstrated that the process of biogas production has a number of strengths and offers a number of social and environmental opportunities. In addition, the study showed that the process of biogas production offers profits for both the environment and the local community. The process of biogas production could also contribute to solving local problems and can be applied for the purposes of providing satisfaction of the social needs on a local scale. The presence of such investments provides a way to manage the putrescible organic waste produced by agricultural and food industry as well as communal one (derived from wastewater plants) in a given area. In this way, new workplaces can be created and the local communities can become self-sufficient while a beneficial impact of the undertaking on the environment can be ensured.

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Produkcja biogazu w aspekcie zrównoważonego rozwoju

Streszczenie

Podstawowymi kierunkami polityki zrównoważonego rozwoju jest inwestowanie w tzw. „zielone" technologie służące do wytwarzania energii pochodzącej ze źródeł odnawialnych. Do nich zaliczyć można biomasę, która przetworzona w procesie fermentacji metanowej może generować biogaz wykorzystywany do celów energetycznych, a mianowicie do produkcji ciepła i energii elektrycznej. Biogazownie już od kilku lat są obecne na polskim rynku produkcji energii. Wg GUS [lit] w 2014 roku w strukturze pozyskiwania energii pierwotnej ze źródeł odnawialnych w Unii Europejskiej biogaz stanowi 7,6%, a w Polsce 2,6%. Istotnym aspektem produkcji biogazu jest wykorzystanie surowców odpadowych z produkcji rolniczej i przemysłu spożywczego m.in. gnojowicy, odpadów poubojowych, wywarów gorzelnianych i in. Działanie biogazowi daje szereg korzyści dla środowiska m.in. na drodze kontrolowanego procesu fermentacji i jego wykorzystania do produkcji energii, umożliwia ograniczenie emisji metanu i innych gazów cieplarnianych. Redukcja ilości odpadów, ochrona środowiska, wypełnianie zobowiązań unijnych i bezpieczeństwo energetyczne potwierdzają, że warto aby gminy w Polsce zainteresowały się możliwym do pozyskania biogazem. W artykule przedstawiono analizę SWOT produkcji biogazu w kontekście zrównoważonego rozwoju. Ocenę czynników (mocnych i słabych stron, szans i zagrożeń) oraz ich intensywność oddziaływania dokonano przy zastosowaniu autorskich skal punktowych. Przeprowadzona analiza wykazała, że proces ma wiele mocnych stron, które mogą przyczynić się do pozytywnych zmian w kontekście środowiskowym i społecznym na szczeblu lokalnym.

Słowa kluczowe: produkcja biogazu, zrównoważony rozwój