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Utilization of Landfill Biogas in the Context of Sustainable Development Based on the Example of Communal Landfill in Opole

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Abstract: This paper presents the results of a study into the application of landfill biogas by applying an example of a biogas power plant situated on-site at the municipal landfill in Opole (MSO). The objective of the study was to analyze the operation of a biogas power plant. During the study, the environmental impact of the facility was assessed. This analysis involved the considerations of a biogas power plant in terms of the social impacts of its operation. An economic assessment was performed, including a comparison of the investment made in this plant with the potential revenues generated from its exploitation. The analysis was performed on the basis of data detailing the amounts of derived biogas and electricity production in the biogas power plant. A number of advantages of the use of the landfill gas are demonstrated along with the impact on the environment in the context of sustainable growth and integration of the social and economic aspects. On the basis of this analysis, we can state clearly that the application of a biogas power plant with the purpose of utilizing the available landfill gas resource forms a technology forms a process that is environmentally-friendly, economically feasible and is characterized by a considerable level of social approval.

Key words: biogas, landfill, biogas power plant

JEL codes: Q01, Q24

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1. Introduction

In a modern society, more and more attention is paid to the issues regarding the depleting resources, degradation of the natural environment and slowdown in the rate of economic development. Hence, it is relevant to the promote the concept of sustainable development. By adopting an approach based on sustainable development in thinking and acting, we always strive to strike a balance between three aspects, i.e. economic, ecological and social ones. The notion of sustainable development is defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" *(United Nations, 1987: chapter 2*). An important and indispensable element of the sustainable development is associated with the conservation of the natural resources and enhancing citizens' quality of life in the future**.**

Nowadays, the interest in renewable energy sources and development of new, environmentally-friendly technologies keeps growing. In this process, emphasis is placed on the application of Renewable Energy Sources (RES) due to the economic, energy and ecological considerations. The application of these types of fuels reduces the hazard to the environment resulting from the emission of greenhouse gases, acid rains in a process coupled with ozone depletion interacting with the climate change. When we deal with the issues pertaining to the sustainable growth, we will purposefully apply the term 'sustainable energy' to refer to the issues pertaining to sustainability in use of resources, their accessibility, use of energy sources, in the context of the smaller damage that is caused to the environment and the society by the new energy utilization. Moving a step further, we can discuss the 'sustainable energy system' which "should be based on a combination of renewable technologies of deriving energy, sustainable transport and fuels, renewable heat, demand decrease, efficiency in energy use and combined technologies of energy production" (Mitchel, 2010: 9).

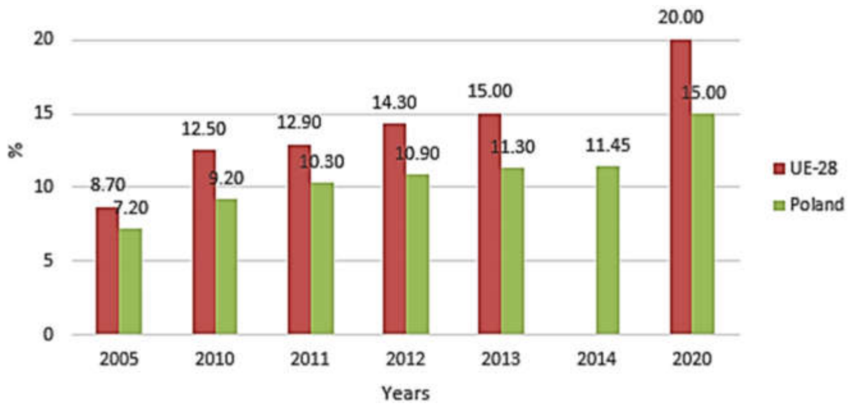
The energy sector in Poland is to a great extent based on very ineffective and outdated technologies involving production of energy from coal. Hence, when new principles are to be implemented in this sector, they need to be based on the principles applying sustainable development, i.e. conversion of the manners in which energy is derived, both in terms of the applied technologies and use of the raw materials. In addition, the energy policy of the EU imposes the adoption of an integrated and comprehensive approach to climate and energy policies. The European Council adopted the guidelines relevant in this context in March, 2007 and the framework of actions that the Community is committed to achieve by the year 2020 includes following goals (Bernat, 2015: 9):

- reduction of greenhouse gas emissions by at least 20% in comparison to the levels of 1990,
- increase of the ratio of renewable energy in all sources of consumed energy to 20%,
- increase of energy efficiency by 20%.

Biogas forms a clean, environmentally-friendly biofuel that is considered as RES, as it is derived from all types of organic matter, including its generation in landfills, wastewater treatment plants and agricultural biogas plants. Some of its advantages are associated with the low cost of production, and the increase of its ratio in the energy consumption by the heating and energy sectors can offer considerable ecological benefits.

The statistical data (Central Statistical Office, 2015) demonstrates that the total ratio of the energy derived from RES in the gross final energy consumption increases year by year. This percentage share was equal to 8.7% in 2005, while in 2014 the ratio increased by 2.75%, whereas the data for the UE-28 show that the ratio was 15% in 2013 and this was an increase by 6.3% in comparison to 2005 (Figure 1).

Figure 1. Percent of energy derived from renewable sources in final energy consumption.



* data for 2020 is a forecast

Source: Study results based on data from Central Statistical Office, 2015.

One of the up-to-date methods of utilizing landfill biogas is associated with the construction of biogas power plants, in which this gas is applied for combustion in a cogeneration system. In this manner, electricity and heat are produced, which can be subsequently applied for the internal electrical load and heat demand of the plant or they can be sold to the electrical grid. Just as for the case of the majority of such investments, biogas plants have a number of disadvantages, which accompany the known benefits. One of the principal drawbacks is associated with the high cost of investment; hence, the number of such installations is still small. In addition, the operation of a biogas plant needs a apply a constant input of organic fuel coupled with the control and supervision of the process parameters.

This type of small biogas power plant was built on-site at the municipal landfill in Opole (MSO). Since the objective of the study is to analyze the activity of a biogas power plant in the context of the sustainable development, it is necessary to consider the social, ecological and economic aspects of its operation. As a consequence of the performed analysis, we can conclude that the exploitation of a bio-fuel power plant with the purpose of utilizing landfill biogas forms a technology that is economically feasible and the idea enjoys a considerable level of social support.

2. Characteristics of landfill biogas

On the basis of data from Central Statistical Office (GUS, 2015), we can learn that the amount of energy production from renewable sources in the overall production of the industrial power sector was equal to 2289 GWh in 2015, with the production of landfill biogas in the volume of 226 GWh, which corresponds to 10% of the total energy that is derived from RES (Table 1). Concurrently, for the case of the heat production, these figures are: 1747 TJ (total heat production) and 67 TJ (total heat production derived from landfill biogas in 2015), i.e. 4% of energy that is derived from RES (Table 2).

Table 1. Electricity production derived from biogas expressed in units of industrial power sector between 2011-2015

Years / Production	2011	2012	2013	2014	2015
	GWh				
Landfill	233.7	236.5	240.7	225.3	226.8
Sewage treatment plant	149.8	193.7	233.5	252.5	275.6
Other	67.7	135.1	215.5	338.4	404.0
Total:	451.1	565.4	689.7	816.3	906.4

Source: Study results based on data from Central Statistical Office, 2015.

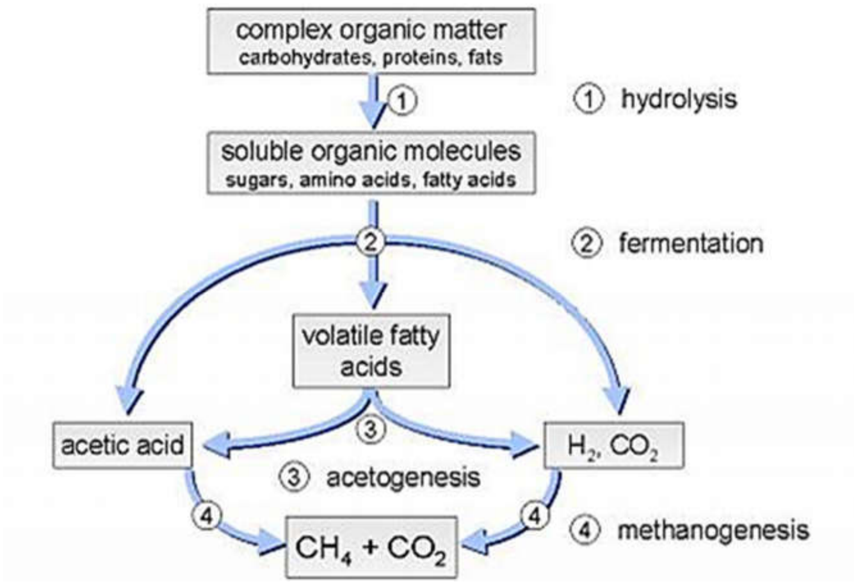
Table 2. Heat production from biogas expressed in units of industrial power sector between 2011-2015

Production \ Years	2011	2012	2013	2014	2015
	TJ				
Landfill	62	69	74	69	67
Sewage sludge treatment	18	35	122	79	198
Other	46	103	174	144	165
Total:	126	207	371	293	431

Sources: Study results based on data from Central Statistical Office, 2015.

Biogas is derived in a biological process based on biomass handling. The most common technique of biogas production involves methane fermentation (Figure 2), where the physico-chemical processes supported by methane bacteria are used to digest organic matter to form gas in anaerobic conditions.

Figure 2. Anaerobic digestion of raw material



Source: Study results based on data: Głodek E. et al., 2007:11.

The classification applied with regard to biogas is a matter of convention and is determined by the raw material that is applied for the production of a biogas. At present, we distinguish the following types of biogas (Central Statistical Office, 2015):

- landfill biogas,
- sewage biogas,
- communal biogas,
- agricultural biogas.

It is estimated that in optimum conditions, degradation of 1 Mg of communal waste can produce around 400 – 500 m^3 of biogas; however, in real conditions this amount is in the range from 50 to 200 m^3. In addition, the most intensive process of biogas production is obtained throughout the first two years following the closure of a landfill bed (Błaszczyk-Pasteczka and Żukowski, 2007: 14).

3. Case of biogas power plant at municipal landfill in Opole (MSO)

The building of the biogas power plant located at the municipal landfill in Opole took the period between 2010-2011 and the project was supported by the EU funding from the European Regional Development Fund. The scope of the project, whose full name was ”Landfill gas recovery and energy utilization from communal landfill in Opole” involved the construction of an installation that was designed to recover and utilize biogas for energy production (Figure 4).

This installation comprises a number of elements:

- A gas field comprising 40 degassing wells,
- Connector container,
- Suction container,
- Gas flare,
- Generator container,
- Biogas power plant with a 450 kW generator unit,
- LV/MV transformer station,
- Electricity infrastructure.

The installation of the biogas power plant derives the gas for energy production from a quarter of the landfill with the surface area of 6.4 ha. The landfill gas is transported into the installation from degassing wells, which are evenly distributed in the area of the quarter. The gas that is derived is first subjected to various processes before it can be utilized for combustion purposes. It is dried and treated and its composition is controlled so as to optimize the level of methane in the biogas.

In addition, the composition of the biogas needs to fulfill a number of requirements that have to be fulfilled for combustion in an engine as imposed by manufacturers of the equipment; hence, the parameters of the biogas are constantly monitored. The contents of CH_4, CO_2, O_2 and H_2S are monitored as well. From the collector, biogas is pumped through a pipeline into a generator chamber type HE-KEC-480/510-PG480. It is a turbocharged, four-stroke spark ignition engine manufactured by Perkins.

As a result of the combustion of the gas-air mixture in the engine, mechanical and thermal energy is derived. The mechanical energy is transferred to the electrical generator, whereas the thermal energy can be recovered with the purpose of its further utilization. The electrical capacity of the generator unit is equal to 450 kW, and its thermal power is 510 kW.

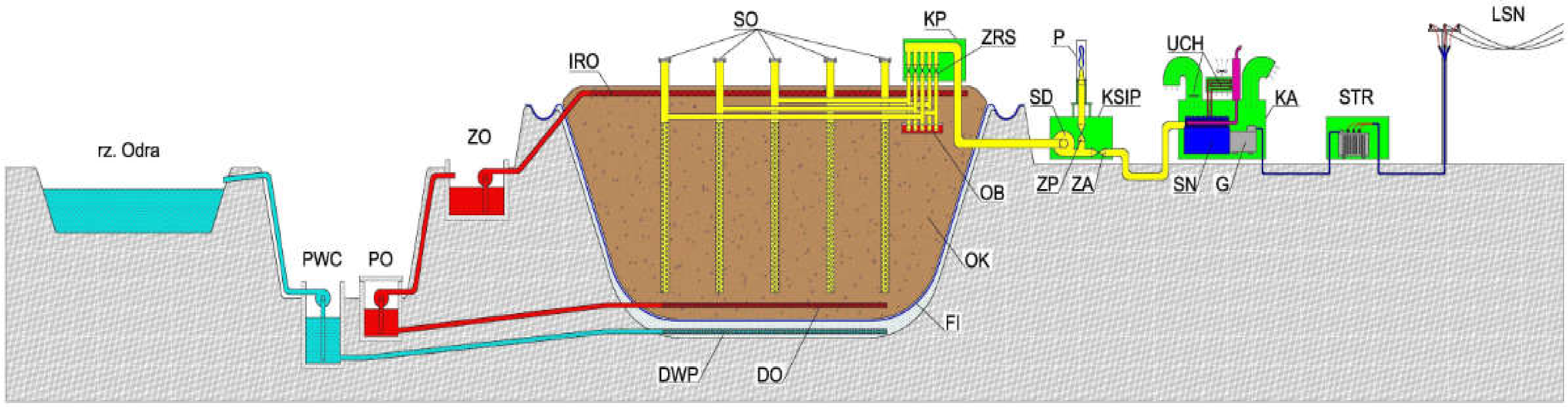
The methane production processes occur spontaneously and constantly so in order to ensure degassing of the landfill during the scheduled and emergency downtimes of the engine, a gas flare was installed with an internal ignition system to enable the system to burn biogas. The diagram of the power generating unit is presented in Figure 3.

Figure 3. View of biogas power plant facilities. The front section of the diagram shows the suction container and gas flare, and power generating unit and transformer are in the background

Source: Koszyk, 2012.

The spatial and functional diagram is presented in Figure 4.

Figure 4. Functional and spatial diagram of the biogas power plant at municipal landfill in Opole (MSO)



DO – leachate drainage DWP – water drainage, FI - waterproof membrane, G - electric generator, IRO – drainage installation of leachate, KA – aggregate container, KP – connected container, KSIP – gas flare container, LSN - transfer line, OB - dehydrator, OK – municipal solid waste, P – gas flare, PO – leachate pump house, PWC – water pump house, SD – suction-blower, SN - driving motor, SO – degassing wells, STR – transformer station, UCH – aggregate cooling system, ZA –aggregate valve, ZO – leachte reservior, ZP gas flare valve, ZRS – wells regulation valves.

Source: Koszyk, 2012.

4. Utilization of landfill biogas produced at municipal landfill in Opole (MSO) in the context of sustainable development

The analysis of the use of landfill biogas as a fuel and the operation of the biogas power plant was performed by application of three considerations involved in sustainable development studies, so as to analyze the environmental, social and economic implications of its operation. The analysis applied the use of the expert assessment.

a) Analysis of environmental aspects

The analysis of environmental aspects was the assessment of all aspects of the positive and negative implications associated with the biogas power plant's impact on the environment. The first step involved a comparison of the impact of the environment between the energy application of biogas in the plant and its uncontrolled emission into the atmosphere. The intensity of the environmental hazard was determined on a point scale from 0 to 3.

These rank corresponding to the intensity are as follows:

- 0 – no impact,
- 1 – small impact,
- 2 – considerable impact.

The hazards that were considered and the results of the comparative analysis of the utilization of biogas and its uncontrolled release into the atmosphere are summarized in Table 3.

Table 3. Evaluation of the intensity of hazard caused by biogas – utilization for energy production and biogas emission into atmosphere

Hazards	**Biogas emission into atmosphere**	**Biogas utilization for energy production**
	Intensity	Intensity
Polution emissions	2	0
Health hazards	2	1
Negative impact on construction	1	0
Increasing the greenhouse effect	2	0
Odor emission	2	0
Noise emission	1	1
Explosive and fire hazards	2	1
Ozone layer depletion	2	1
Total:	14	4

Source: Study results.

Throughout the analysis of the biogas emission into the atmosphere, a considerable level of its impact on the living organisms was assumed resulting from the emission of pollutants. For instance, its carcinogenic effect is reported (Ciupryk and Gaj, 2004: 123-126). The uncontrolled emission of the biogas into the atmosphere affects the soil contamination, and results in its degradation and has an adverse effect on the plants as a consequence of the diffusion of biogas into the root structure. In addition, the emission of biogas can lead to the pollution of the ground water. Moreover, the migrating gas can accumulate in the parts of the buildings such as cellars and well chambers thus leading to a hazard of explosion and progressive deterioration of the building structure.

Due to the application of biogas, the consumption of fossil fuels can be reduced; hence, the emission of greenhouse gases can decrease as well, including CO_2, SO_2, NO_x, CO, C_6H_6 (benzene), C_8H_{10} (xylene) and C_7H_8 (toulene) (Grzesik, 2006: 26-36). In addition, the emission of odors from the landfill can be minimized, through which the negative impact on the environment and living organisms can be reduced.

On the basis of the adopted intensity scale of the environmental impact, the maximum score that can be obtained is equal to 19. For the energy use of biogas, the result was 4, whereas for the emission of the biogas directly into the atmosphere, the score representing the intensity of the environmental hazard was over three times greater. As a consequence, we can state that the utilization of biogas for energy production can be considered as a pro-ecological technology.

b) Analysis of economic aspects

The analysis of economic aspects was performed on the basis of the information regarding the operation of the biogas power plant installation located at municipal landfill in Opole (MSO). On the basis of an analysis of data in Table 4, we can note that the amount of the biogas that is used decreases year after year; hence, the volume of produced energy decreases as well. A variety of factors have an impact on the production of biogas, including weather conditions, moisture content in the waste mass, adequate control of leachate recirculation, degree of its fragmentation, the manner in which it is conditioned and the age of the deposited waste on the landfill site. Table 5 contains a summary of the revenues generated by the sale of the electricity produced in the biogas power plant investigated in this paper. The revenues were calculated by taking into account the mean prices of electricity in the analyzed period. Such prices are given by the President of the Energy Regulatory Office (URE) in accordance with the law on the renewable energy sources. The sales prices of electricity in the competitive market that were obtained from the Energy Regulatory Office (URE) in the analyzed period were as follows:

- in 2013 – 181.55 PLN/MWh,
- in 2014 – 163.58 PLN/MWh,
- in 2015 – 172.75 PLN/MWh.

Table 4. Consumption of biogas and generated electricity in the installation of the bio-energy plant in the period 2011-2015

Term	Biogas consumption	Energy	Biogas consumption	Energy	Biogas consumption	Energy
	thous. m^3	MWh	thous. m^3	MWh	thous. m^3	MWh
	2013		2014		2015	
I	307.8	525.1	372.7	683.2	308.6	576.9
II	344.5	567.4	337.3	594.0	351.3	586.6
III	390.5	674.3	321.4	572.0	227.5	336.9
IV	381.5	684.5	222.7	494.6	394.0	686.3
Total	**1,424.3**	**2,451.2**	**1,311.4**	**2,343.9**	**1,281.4**	**2,186.7**

Source: Study results

Table 5. Revenues from the sale of electricity in the period 2013-2015

Term	Revenue	Revenue	Revenue
	thous. PLN	thous. PLN	thous. PLN
	2013	2014	2015
I	95.3	111.8	99.7
II	103.0	97.2	101.3
III	122.4	93.6	58.2
IV	124.3	80.9	118.6
Total	**445.0**	**383.5**	**377.8**

Source: Study results

The local transmission system operator is legally obliged to purchase the electricity generated from the renewable energy sources connected to the distribution network located at the area that is within the area of operator's activities (Law Journal 2016: item 925); hence, the energy that is generated in the biogas power plant is transferred into the national electricity grid and generates revenues for the landfill operator.

Besides the sales of electricity, on the basis of submission of an application, a guarantee of origin (green energy certificate) can be given to an electricity producer. Such certificates are issued by the President of the Energy Regulatory Office. This type of certificates form a guarantee that the energy was derived from renewable energy sources. As a result of a measure created in Energy Law and Law on RES with the purpose of promoting renewable energy production, it is possible to sell these certificates. The trade the property rights related to the origin certificates provides RES producers the opportunity to generate an additional income arising from the sales of RES-derived energy apart from the revenues that are gained from the sales of the physical product formed by electricity itself.

The calculation of the potential of receiving revenues from the sales of certificates of biogas origin applied the mean annual price of property rights of green certificates registered by Polish Power Exchange SA. during trading sessions. In the respective years, these prices were equal to:

- in 2013 – 230.00 PLN/MWh,
- in 2014 – 186.53 PLN/MWh,
- in 2015 – 123.60 PLN/MWh.

The calculated values of the potential revenues from sales of the certificates of origin are summarized in Table 6.

Table 6. Total of potential revenues from sale of the green certificates

Years	**2013**	**2014**	**2015**
Revenue, thous. PLN	563.8	437.2	270.8
Total, PLN			**1,271,270.3**

Source: Study results.

In summary, the value of the project was equal to 6,899,326 PLN, the EU funding was 2,795,558 PLN, and the generated revenues were equal to a total of 1,206,183 PLN throughout 2013 – 2015 from the sales of electricity into the grid and 1,271,270 PLN from the sale of the green certificates. By analyzing this data, we can conclude that this type of installation will be able to repay its cost after 5 years in the analyzed schedule of operation, i.e. excluding the use of the thermal energy.

c) Social aspects

The idea of utilizing the landfill biogas for energy production receives positive public reception. The production of biogas and its further utilization forms a system that concurrently enables the facility to apply natural resources, neutralize organic waste and produce renewable energy, and thus, this production combines the energy, environmental and agricultural benefits and provides social benefits.

The most important considerations affecting the reception of the installation of the biogas power plant are as follows:

- it secures the energy security of the region – since the volume and parameters of the energy production keep at a constant level,
- it provides a local and ecological source of energy,
- it offers a continuous energy supply to customers – as the production of biogas is non-stop,
- it leads to the reduction of methane emission into the atmosphere – thus offering the positive effect on the environment and reduction of the harmful odors in the area that surrounds the landfill.

5. Conclusions

At present, it is essential to follow the idea of the sustainable development in all branches of industry. Such activities promote both social and economic development. Hence, it is important to implement the principles of sustainable development in the power industry as well. The current state of the technology in the energy sector is to a great extent based on ineffective and outdated technologies energy production from conventional fuels and this forms a hazard to the natural environment. To minimize the negative environmental impact, it is important to invest in the installations applying renewable energy sources, such as the use of landfill gas. Undoubtedly, an advantage is this application is associated with environmental considerations, such as the reduction of greenhouse gas emissions and social benefits resulting from its utilization. Another step towards the sustainable development is associated with the use of the up-to-date technologies. The installation of the biogas power plant located at municipal landfill in Opole (MSO) offers an example of an installation capable of utilizing landfill gas. As a result of the energy potential of the gas, the derived biogas can be applied for production of electricity and heat which can be further used to meet the demand of the facility or sold into the domestic distribution network and district heating system.

In summary, we can say that the application of this type of technology in the production of energy is in conformity with the principles of the sustainable development. The use of the biogas derived from a biogas power plant leads to a considerable reduction of the environmental hazard in comparison to its emission into the atmosphere, and this affects the social reception of the installation and increases the local added value. By analyzing the economic aspect of the operation of the biogas power plant in Opole, we can state that the installation is economically feasible and will offer profits from energy production after 5 years of operation, which is a remarkably short period for this type of installations.

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Wykorzystanie biogazu składowiskowego w aspekcie zrównoważonego rozwoju - bio-elektrownia MSO w Opolu

Artykuł przedstawia sposób wykorzystania biogazu składowiskowego oraz działanie małej bio-elektrowni na przykładzie instalacji MSO w Opolu. Celem pracy było wykonanie analizy działania bio-elektrowni w świetle aspektów zgodnych z zrównoważonym rozwojem. Analizę wykonano na podstawie uzyskanych danych dotyczących produkcji energii elektrycznej i ilości spalonego gazu w instalacji bio-elektrowni oraz w wyniku przeprowadzonego przeglądu literaturowego. Ukazano szereg zalet wykorzystywania biogazu składowiskowego, pozytywny wpływ na środowisko oraz zachowanie równowagi i integracji pomiędzy działaniami społecznymi oraz ekonomicznymi. W wyniku przeprowadzonych prac można z powodzeniem stwierdzić, że zastosowanie bio-elektrowni w celu utylizacji biogazu składowiskowego należy do technologii przyjaznych środowisku, opłacalnych ekonomicznie oraz charakteryzujących się wysokim poparciem społecznym.

***Słowa kluczowe**:* biogaz, składowisko odpadów, bio-elektrownia.

Kody JEL: Q01, Q24

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