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Green energy for the Province of Warmia and Mazury from biogas*

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ABSTRACT

Currently in Poland the most widely used material for the production of electricity is fossil fuels. However, due to an increase in their prices and the tightening of European Union regulations on emissions of greenhouse gases, there are tendencies to transform the energy sector through the implementation of technologies based on alternative source of energy. The main focus is, therefore, on renewable energy source. In recent years, Poland has increased interest in the investments in renewable energy sources to fulfill the guidelines of the EU energy policy, which obliges Poland to obtain a 15% share of renewable energy sources in final energy consumption by 2020. One of the preferred state policy activities related to the production of energy from renewable sources is biogas production and cogeneration of electricity and heat. The simultaneous production of heat and electric or mechanical energy during the same technological process is called Combined Heat and Power (CHP). The Province of Warmia and Mazury is a ”green region”, which is why biogas is a solution that can ensure future energy security for the whole province. The methodological approach included in the article is to determine the potential energy that can be obtained from biogas cogeneration process. To this end, an analysis of Central Statistical Office data was performed as well as an analysis of available reports and studies for the Province of Warmia and Mazury, in the context of determining the energy potential of biogas cogeneration. As a result, the general method has been developed that allows the determination of the average theoretical potential for energy production from biogas cogeneration process. In addition, the article presents an illustrative diagram of a biogas plant with CHP system.

INTRODUCTION

Several simultaneously occurring phenomena underlie the need for development of environment-friendly technologies of energy production. Firstly, the dynamic technological development has caused that nowadays no one can imagine life without present facilities such as the electricity, which is mainly produced from fossil fuels. This in turn has led to the dependence of the humanity on these natural resources. When coupling this with a continuous increase of the Earth's population, these deposits seem at risk of depletion in the near perspective. Moreover, monopolistic cartels dictate high prices of these raw materials. Taken together these two factors have become the impulse to search for alternative fuels, mainly those whose resources are significant or renewable.

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Secondly, in the 1960-ies, the world began to pay attention to the problem of air pollution caused by many factors, also by a huge development of the energy sector. This is due to excessive energy emission of greenhouse gases into the atmosphere and the progressive degradation of water and soil. In view of the threat of environmental disaster hanging over the Earth, Europe and the world began to form new political agendas that define the solutions to the problem of environmental pollution. The result is a continuous tightening of the acceptable emission standards of energetic greenhouse gases into the atmosphere, which in turn causes, that the conventional ways of obtaining electricity slowly cease to be sufficient. The solutions focus on the rational production of goods in the processes of relatively higher efficiency and lower environmental risks. In this context, it is reasonable to transform the energy sector dominated by conventional technologies, based mainly on fossil fuels, by improving the cogeneration of electricity and thermal energy, and dissemination of technologies based on alternative sources of energy. Researches on the use of alternative fuels are focused primarily on gaseous and liquid fuels. The focus is on these fuels whose resources are considerable or renewable.

In recent years, Poland has increased interest in the investments in renewable energy sources to fill the guidelines of the EU energy policy (European Directive 2009/28/EC of 23 April 2009), which obliges Poland to obtain a 15% share of renewable energy sources in final energy consumption by 2020 (Minister of Economy 2011).

An activity related to the production of energy from renewable sources is biogas production and cogeneration of electricity and heat. This activity is one of the preferred by state policy. The simultaneous production of heat and electric or mechanical energy during the same technological process is called *Combined Heat and Power* (CHP).

These actions lead to the development of the biogas sector, which can be directly and indirectly applied to all three energy end-markets, i.e., electricity, heat and transport. Important for the environment is the fact that within the past 200 years the methane concentration in the atmosphere has increased from 0.7 to 1.7ppm, which contributes in 18% to the greenhouse effect (Oniszk-Popławska et al. 2003).

It is estimated that about one third of methane emission comes from agriculture, and livestock manure are the source of 20% of its total emission. The warming factor for methane is 21-fold greater than the value of this coefficient for CO_2. This means that preventing the emission of 1 ton of methane is approximately equivalent to avoiding the emission of 21 tons of CO_2 (Oniszk-Popławska et al. 2003).

Production of electricity and heat in cogeneration is one of the most effective ways to increase the efficiency of conversion of the chemical energy of fuels, and thus its savings in comparison with the processes of production of electricity and heat implemented separately. The benefits of this approach are improved energy efficiency, primary energy savings, and a reduction of emission of harmful substances.

The current energy situation and the current energy problems in the Province of Warmia and Mazury are similar to these presented above. Referring to the arguments presented above, it was found possible to use the potential of Warmia and Mazury Province for the production of biogas from organic materials of agricultural origin, and then to use that gas in a cogeneration process to produce electricity. As a result of these considerations, it was found feasible to ensure the security of the energy supply to the region in the future.

THE PROCESS OF BIOGAS GENERATION

Biogas is an energy carrier produced from organic matter (biomass) in the process of anaerobic fermentation. The following types of biogas can be distinguished depending on its production method:

- landfill gas, obtained from the digestion of waste in landfills,
- gas from sewage sediments, produced by anaerobic fermentation of sewage sludge,
- agricultural biogas obtained from biomass from energy crops and crop residues or animal waste,
- biogas derived from waste from slaughterhouses, breweries and other food industries (Duda et al. 2011).

According to the Directive of the European Parliament and Council 2009/28/EC of 23 April 2009 on the promotion of energy from renewable sources, the concept of biomass is defined as "the biodegradable fraction of products, waste or residues from 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".

The biogas is mainly produced from organic material of agricultural origin (such as livestock manure, energy crops and agricultural waste), and also industrial waste. Physically, biogas is a gas solution consisting mainly of methane and carbon dioxide, as shown in Table 1.

The proportion of the individual components, the qualitative composition and properties of biogas depend on many factors, the most important of which are the initial composition of the raw material subjected to the process of biodegradation, moisture content of organic matter, temperature, pressure, and method of implementation of this process. It is worth noting that the percentage of methane in the biogas constitutes the calorific value of the fuel, i.e., the greater the participation of methane, the higher the calorific value of biogas (Schulz and Eder 2001).

Table 1. The average composition of biogas (Schulz and Eder 2001).

Component	Concentration
Methane (CH_4)	50–75%
Carbon dioxide (CO_2)	25–45%
Hydrogen sulfide (H_2S)	20–20 000ppm
Hydrogen (H_2)	<1%
Carbon monoxide (CO)	0.0–2.1%
Nitrogen (N_2)	<2%
Oxygen (O_2)	<2%
Others	traces

The production process of biogas includes four stages. First is the hydrolytic phase, in which the decomposition of macromolecular organic compounds takes place to simpler soluble compounds. The second stage is the acidogenic stage (acidogenesis), including the production of short-chain organic acids (mainly volatile fatty acids) as well as alcohols and aldehydes. The next step is the acetogenic phase (acetogenesis), wherein acetic acid is formed together with CO_2 and H_2. And the last step is the methanogenic phase (methanogenesis), during which biogas is generated (CH_4 and CO_2) (Piątek 2005).

A set of equipment for the production and storage of biogas (fermentation tank with equipment and a tank for biogas) is referred to as a biogas plant. In the technological cycle of a typical biogas plant, four different stages are distinguished, regardless of the type of operation:

- supply, storage, treatment, transport and introduction of substrates,
- obtaining biogas,
- storage and eventual treatment of post-fermentation residues (digestate) and their disposal,
- storage, treatment and use of biogas (Jäkel 2003).

Biogas can be used both for stationary and transport purposes, and to supply the natural gas grid. Due to the existing support mechanisms for "green energy", the most preferred technique for the use of biogas is primarily its utilization in associated systems for the production of electricity and heat production and sales of generated electricity to the grids. Electricity in a simple way and with high efficiency can be converted to any other form of energy.

A simplified schematic representation of a biogas plant with CHP system is shown in Figure 1.

Typical cogeneration system consists of a gas engine, 3-phase synchronous generator, pre-muffler exhaust, after-treatment system, starting system (batteries), control cabinet, and an internal air circulation.

Direct use of biogas obtained in the process of anaerobic fermentation to power the motors of vehicles is not possible, mainly due to the undesirable components present in the reaction, which reduces the efficiency of biogas combustion as a fuel. Therefore, the biogas is subjected to purification. The methane content in biogas to be used in internal combustion engines should not be less than 96%, the concentration of water vapor should be less than $15mg \cdot m^{-3}$ and the hydrogen sulfide content should not exceed $100mg \cdot m^3$. Solid particles in the gas, greater than 40 microns, also cannot be present as they can pose difficulties in engines operation (Piętak et al. 2012). In order to meet such high demands, solutions tailored to the needs should be used, paying attention to the costs at the same time. An important factor is also the amount of energy needed to carry out the method of purification.

Raw biogas, immediately after the process of anaerobic fermentation, can be purified using a variety of methods to the quality of high-methane natural gas, low-methane natural gas, replaceable gas or replacement gas. The difference between the replaceable gas and replacement gas is that the former can be mixed with natural gas in any proportion since it has the same characteristics as the natural gas, while the replacement gas, can be added only in limited amounts. Technology for the purification of biogas consists of biogas desulfurization step, then removal of carbon dioxide from biogas, and a biogas drying step.

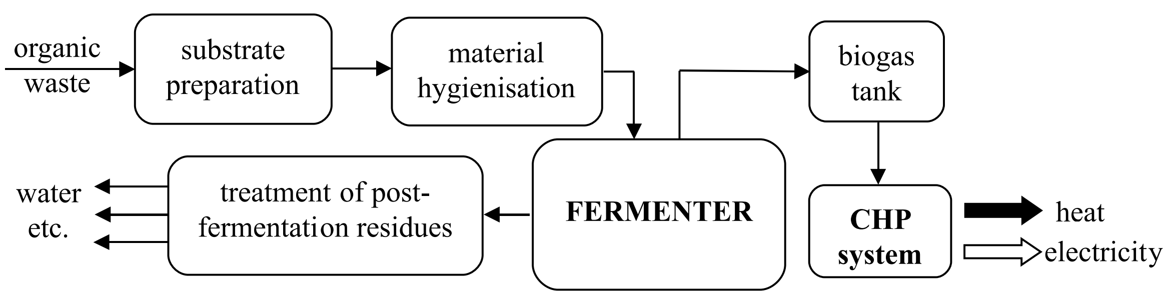

Figure 1. Schematic diagram of a biogas plant with CHP system (Piątek 2005).

ENERGY SECURITY FOR THE PROVINCE OF WARMIA AND MAZURY

As already mentioned, the Province of Warmia and Mazury is a "green region", and therefore it is feasible to acquire a significant amount of organic material of agricultural origin in this area. This material has great potential. The main discussion is focused on the use of livestock manure and energy crops.

In the case of livestock manure, it is characterized by variable composition depending on maintenance and feeding, and the amount of water used. Organic substances have different rate of decay and different amounts of biogas resulting from decomposition of biomass.

Currently, high quantities of biogas are produced from livestock manure with the addition of energy crops (dedicated crops), such as grass, clover, potatoes, corn, broad bean, rye, fodder beet, sugar beet, onion, mustard, pea, kohlrabi, cabbage, cauliflower, wheat, oats, barley, sorghum, rape, squash, and sunflower. They can be used in the form of whole plants or separately, fruits or tubers and leaves, seeds, or after processing in the form of silage or straw. In general, however, for purely economic reasons, firstly organic waste and then dedicated crops are used for methane fermentation.

To determine the average theoretical capacity of energy production, a general method was developed, which is presented in Figure 2.

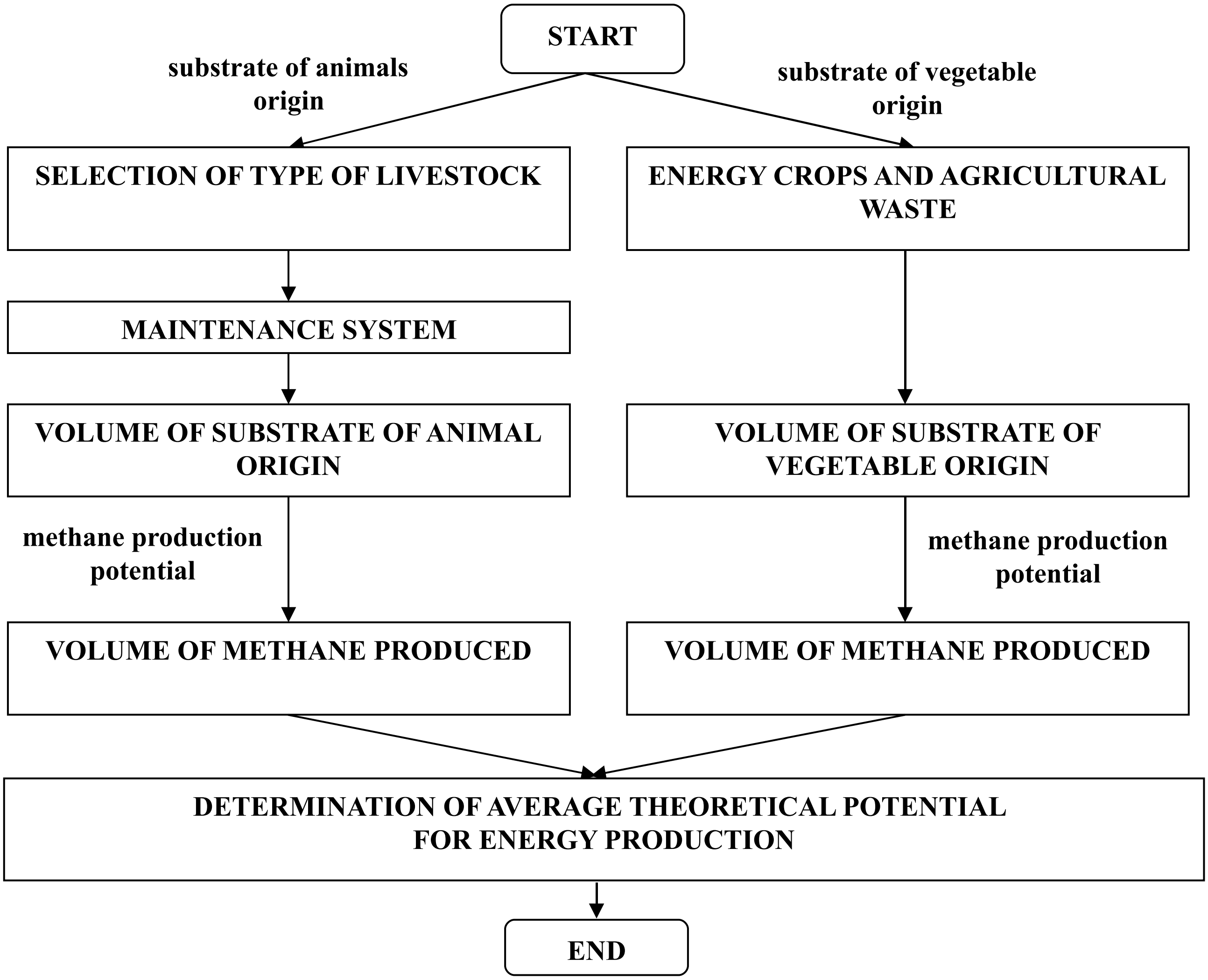

Figure 2. General method for determination of the average theoretical potential for energy production.

To use this method it is necessary to introduce the basic data, like:

- the characteristic of waste production by 1 piece of various farm animals (depending on the system of keeping),
- the characteristic of substrate of agricultural origin together with the potential of biogas production.

Table 2. Average values of waste production by 1 piece of the various farm animals (the Ministry of Agriculture and Rural Development, the Ministry of Environment 2002).

Farm animals	System of keeping			
	deep bedding	shallow bedding		without bedding
	manure [tonne·y^{-1}]	**manure** [tonne·y^{-1}]	**liquid manure** [m^3·y^{-1}]	**slurry** [m^3·y^{-1}]
Cattle	13.83	7.420	3.82	20.67
Swine	4.34	1.940	2.14	2.96
Poultry	-	0.043	-	-

- no data

The characteristic of waste production by 1 piece of the various farm animals are presented in Table 2. The characteristic of substrate of agricultural origin together with the potential of biogas production are presented in Table 3.

Table 3. The characteristic of substrate of agricultural origin together with the potential of methane production (EU-Agrobiogas 2007-2010).

Substrate of:			Substrate and its potential		
			Percentage content of dry matter in 1 tonne of substrate	**Percentage content of dry organic matter in total dry matter**	**Potential of methane production from 1 tonne of dry organic matter (d.o.m.)** [m^3·tonne$^{-1}_{d.o.m}$]
animal origin	**cattle**	**liquid manure**	9.5	77.4	225.5
		manure	23.7	76.4	249.4
		slurry	2.1	60.0	222.5
	swine	**liquid manure**	6.6	76.1	301.0
		manure	23.8	79.9	228.0
		slurry	2.1	60.0	222.5
	poultry	**manure**	30.3	72.7	230.0
vegetable origin	**straw**		87.5	87.0	387.5
	hay		87.8	89.6	417.9
	grass - silage		40.3	83.4	396.6
	potatoes - leaves		25.0	79.0	587.5
	rape - silage		50.8	87.6	376.5

Using this method, the data contained in the materials of Central Statistical Office (2012) (data concern the end of 2011) and government materials (population of livestock, manure production by the various farm animals, the volume of waste from energy crops and agricultural waste), the average theoretical potential for energy production was determined for the Province of Warmia and Mazury. The outcome of this analysis is presented in Table 4.

Table 4. Average theoretical potential for energy production for the Warmia and Mazury Province.

Substrate of:		**Quantity** [10^3 pieces]	**Waste** [10^3 tonnes·year-1]	**Average theoretical potential for energy production** [GWh·year^{-1}]
animal origin	**cattle**	427.80	5201.96	1871.28
	swine	608.60	1381.01	487.87
	poultry	7010.30	301.44	140.05
vegetable origin	**straw**	-	158.42	428.53
	hay	-	541.30	1630.28
	grass - silage	-	1011.46	1236.35
	potatoes - leaves	-	51.86	55.18
	rape - silage	-	28.77	44.20

- no data

As mentioned earlier, the most effective way of generation of electricity and heat is through cogeneration. Electrical efficiency in cogeneration is from 30% to 40% (depending on the producer). The value used in the calculations is 38%. Based on these data, theoretical electrical power can be calculated that can be obtained based on the average theoretical potential energy for the whole Province.

SUMMARY

The electricity consumption of the entire Province of Warmia and Mazury in 2011 stood at 3423 GWh. The performed calculations show that using only selected substrates of vegetable and animal origin to produce biogas, and then using only methane for cogeneration, theoretically 2239.62 GWh of electricity can be obtained, which accounts for 65% of the electricity demand in the Province. Adding other agricultural and industrial waste, even 100% of the annual electricity demand could be reached throughout the Province of Warmia and Mazury. To achieve this effect, it is necessary to establish a number of large biogas plants in the province together with cogeneration systems. Currently in the Province of Warmia and Mazury there is the biogas plant in Boleszyn. In the nearest future, it is expected, that the next 6 investments will be completed. It is still necessary to develop a process of collection, storage and disposal of such wastes. The heat produced in this process can be used to the own needs of biogas plants.

In addition, the implementation of biogas plants results in positive outcomes, mainly ecological ones. The key benefits include the reduction of uncontrolled greenhouse gas emissions, thanks to the utilization of waste for fuel production, and emission reduction through the use of this fuel for energy production (fossil fuel replacement).

Additionally, stable and efficient natural fertilizer obtained in biogas plants facilitates the recycling of nutrients in the soil and reduces the need for chemical fertilizers. Reduction of the fertilization with manure helps to reduce the spreading of biological hazard and the contamination of groundwater and soil.

Biogas plants perfectly fit into the idea of organic farming (sustainable), offering the opportunity to meet our own energy needs (and the potential sale of surplus to the grid) as well as the re-use of nutrients to fertilize the soil when disposing waste. At the same time, the economic benefits of the above savings can be achieved with the production of high-quality commercial products (electricity, fertilizer concentrate), from the provision of commercial services of waste disposal and other, such as sale of CO_2 emission limits and reduction of fossil fuel use. Economic success, however, is conditioned by the scale of the project, logistics, and the right choice of technology. Numerous potential environmental, energetic and economic benefits of the use of anaerobic biodegradation resulted in increased interest in this type of technology in Poland.

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