Research article

Economic analysis for biogas plant working at sugar factory

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Abstract: *Biogas is produced by the biological processes of anaerobic methane fermentation. It is a mixture of methane, carbon dioxide and trace amounts of other gases. By-products of the sugar industry are an efficient source of agricultural biogas. Sugar beet pulp and waste mass plant is characterized by a high content of dry matter and organic dry. The purpose of this article was to develop the economic analysis for biogas plant working at sugar factory and to show the energy balances and material and then calculated the main economic indicators such as Cash Flow (CF), Net Present Value (NPV), Internal Rate of Return (IRR) and Discounted Payback Period (DPP). It was found that the biogas plant operating at a sugar factory can be a profitable investment and DPP amounted to 8 years. However, these results are estimates and in reality they may changed.*

Keywords: *biogas plant, sugar industry, economic analysis.*

Introduction

The sugar factories among of others food-industry stand out with specific heat and electric energy economy. The process of sugar production is permanently integrated with the energy economy. Currently, Polish sugar plants have a processing capacity reaching up to 12 000 tons of beet per day. During elaborate production a large amount of energy is needed and a lot of waste is produced. Residues after production, the substances or materials are partially processed. Transformation them is not the aim of final step of production process but it is a side effect of manufacturing process [1]. In sugar factories a series of valuable by-product, such as molasses, pulp or carbonation lime are formed. Above-mentioned by-products are valuable substrates, which can be subjected to further biotechnology process. One of possible application of sugar pulp can be using it as a substrate for biogas production.

Sugar beet pulp, in large quantities, accumulates as a by-product in sugar factories. The processing of 1 ton of beet produced 250 kg of sugar beet pulp, with a water content of about 75-80% [2]. They are commonly used as silage or dried animals' feed [3]. Sugar beet pulp mainly consists of carbohydrates, like cellulose (22-30%), hemicellulose (24-32%), pectin (24-32%) and lignin (3-4%) [2]. By-products from sugar beet industry are classified as efficient source of biomass. Using it for energy production provides the potential to reduce carbon dioxide emission and it may lead to the reduction of global warming[4]. In the process of anaerobic digestion the biomass can be converted into biogas. Anaerobic fermentation is the biological process, where organic matter is degraded by microorganisms. As a result, microorganisms produce a gas mixture called biogas [5]. The mixture is consisted of methane, carbon dioxide, hydrogen sulfide, nitrogen, oxygen, hydrogen and water. The largest percentage share in composition is methane (50-70%) and carbon dioxide (25-45%). The other gases are present in trace amounts, depending on process flow and used kind of organic matter [6].

The aim of this study is economic analysis of the performance of anaerobic digestion of a given biogas plant. A scenario analysis is carried out on the basis of a feasibility study of biogas plant using byproducts from sugar factory. The plant located in central part of Poland forms the basis for our analysis. The factory is a relatively large plant with an installation capacity of 4 600 Mg sugar beets of input on an daily basis. This paper analyses the economic performance of anaerobic digestion of a given feasibility study biogas plant based on cash flow (CF), net present value (NPV), internal rate of return (IRR) and discounted payback period (DPP). A scenario of technical analysis is carried out based on material and energy balance to identify feedstocks that optimize biogas production and to determine the amount of energy production.

Experimental

Subject matter and scope of research

The Subject of study on working biogas plant was carried out on the basis information from some of a sugar plant included in Polish Sugar Company and fulfilled by literature data. Therefore presented calculations are estimated values and they do not guarantee obtaining the assumed production of biogas. Scope of the research includes technical and economic matters. This issue depends on plant size, substrate type and of their stage of the technology.

In order to technological analysis, material and energy balance was performed. The analysis is assumed by application of sugar beet pulp and waste plant mass as a substrate directed to the biogas plant. Expected amount of substrate supplied is 53 275 Mg. Product properties are shown in table 1. The biogas plant will operate all year for around 250 working days, in conditions of mesophilic while maintaining the temperature 37°C ± 1°C, based on a quasi-continuous feeding the digester.

Table 1. Data relating to substrate

Type of raw material	Beet pulp	Mass of waste plant
Amount of substrate , Mg	50 000	3 257
Dry matter, %	20	15
Organic dry matter, %	96	80
Yield of biogas, $m^3/Mg_{O.D.R.}$	540	320
CH_4 content, % vol.	70	55

Sensitive data, made available by the management board of a sugar plant included in Polish Sugar Company and fulfilled by literature data [7, 8].

For the purposes of economic analysis, indicators of investment efficiency such as Cash Flow (CF), Net Present Value (NPV), Internal Rate of Return (IRR) and Discounted Payback Period (DPP) were used. Capital expenditures and operating costs were estimated on the basis of a calculator biogas Mazovian Energy Agency.

Working of biogas plant will allow to obtain income from the sale of surplus energy. In this case, it was assumed that the thermal energy will be used up for the purposes of factory. Therefore, in the analysis of revenue, only electricity excess was taken into account. The average price sales of electricity produced in high efficiency cogeneration in 2014 amounted to 163.58 PLN/MWh. Additional economic benefits for project may bring sales of energy certificates from production of electricity and heat from renewable sources. Proceeds from energy certificates are calculated from all produced energy. Assumed for calculations average trading price in 2015 green and yellow certificates, which were consecutively 162 PLN/MWh and 121.63 PLN/MWh [13, 14].

Methods

The amount of produced methane is the product of available substrates, dry matter and organic dry matter content as well as potential yield of methane, given by the formula [9]:

$$M = O \times DM \times ODM \times P,\ m^3/year$$

where:

M – annual production of biogas, m^3/year,
O – annual amount of substrate, Mg/year,
DM – percentage of dry matter content in the substrate 1 Mg, %,
ODM – percentage of organic dry matter in dry matter, %,
P – potential of methane production, $m^3/Mg_{O.D.M.}$.

With the purpose of estimated the energy balance total chemical energy production from methane was calculated. In calculations the caloric value of methane was calculated, which is 9.17 kWh/m^3 [10]. It was compute according to the formula (2):

$$E = M \times C$$

where:
E – total amount of chemical energy of the resulting methane, kWh/year,
M – production of methane within year, m^3/year,
C – caloric value of methane 9.17, kWh/m^3.

Evaluation of the electricity and heat production requires the determination of nominal power cogeneration system. For this purpose following assumptions were adopted [12]:

- electrical efficiency is 39.2 %,
- thermal efficiency is 43.6 %,
- efficiency total is 82.8 %,
- engine running time per year 8000 h.

The nominal power cogeneration (P_{nom}) system was calculated using the formula [12]:

$$P_{nom} = \frac{E_{tot} \cdot \eta}{T_p}$$

where:
E_{to} – total energy contained in fuel, MWh,
η – energy conversion efficiency of thermal / electrical, %,
T_p – loading time of biogas, h.

CF is a statement of revenue and expenditure monetary. It is presented in the form of net profit for the particular time of the investment operation, e.g. one year. Furthermore, lifetime of the investment should be estimated, which turns a profit [5, 6]. In the calculations 15-year life of the biogas plant was assumed. NPV determinate the current rate of investment taking into account the changes in the value of capital over time. Universally recognized principles of assessing the profitability of investment projects determine that the investment is profitable when NPV is higher or equal to zero [11]. Applied discount rate for the analyzed investment was 5%.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t}$$

where:
CF_t – balance of cash flow in period t,
n – duration of the project,
r – the level of discount rate, %
t – time unit.

IRR is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR can be calculated from the formula [11]:

$$\sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} = 0$$

DPP gives number of periods, after which the discounted receipts associated with the project align with discounted expenditure. DPP can be calculated from the formula [11]:

$$\frac{\sum_{i=1}^{n} CF_i}{(1+r)^n} = 0$$

where:
CF_i – the balance of cash generated in i - this period,
n – number of operation periods of the project,
r – the level of discount rate, %.

In this article calculation of indicators IRR and NPV were made using a formula functions included in Microsoft Excel 2010.

Results and Discussion

Technological analysis has allowed to estimate the size of a biogas plant with a capacity of 1.7 MWt and 1.8 MWel. Table 2 and 3 presents technical results of described scenario, showing material and energy balances. It was estimated that the annual production of biogas will be 5 309 069 m^3, including the methane content will be 3 697 588 m^3. Sources of literature say it is that the most common substrate used in biogas plants is corn. However, based on the presented calculations, it can be concluded that by-products of the sugar industry are an efficient source of agricultural biogas. Sugar beet pulp and waste mass plant are characterized by a high content of dry matter and organic dry. These properties are important for the methane fermentation process, and more precisely, for bacteria leading this process.

Table 2. Summary of the material balance

Type of raw material	Beet pulp	Mass of waste plant	Sum
Amount of substrate per year, Mg/year	50 000	3 257	53 257
Annual production of biogas, m^3/year	5 184 000	125 069	5 309 069
Annual production of CH_4, m^3/year	3 628 800	68 788	3 697 588
Amount of digestate per year, Mg/year	42 500	2 768	45 268
Total chemical energy of the resulting methane, MWh	33 276	631	33 907

Table 3. Summary of the energy balance

Annual gross heat production,	GJ/year	48 960
Annual gross electricity production,	MWh/year	14 400
Consumption of electricity for the purposes of process,	GJ/year	1 296
Consumption of heat for the purposes of process,	MWh/year	14 688
Annual production of net heat,	GJ/year	47 664
Annual electricity net,	MWh/year	13 104

In order to determine the indicator CF, the costs associated with the investment in the creation of installation and it operation were estimated. The potential value of revenue during the operation of the system in a given year was also estimated. Investment expenditures was determined by the calculator biogas Mazovian Energy Agency, and was amounted to 24.46 mln PLN. Following recommendations of Mazovian Energy Agency, the costs related to the operation and maintenance of installations represent 10% of the investment which amounted at 2.45 mln PLN. Revenues were estimated based on the sale of surplus electricity production. Average price from the sale of electricity produced in high efficiency cogeneration in 2014 amounted to 163.58 PLN/MWh [13]. Moreover benefits from the sale of energy certificates for the production of electricity and heat from renewable sources were estimated. Agricultural biogas plant, which uses only the substrates of agricultural origin, can apply for a green and cogeneration certificates at the same time. Namely extra for each MWh of electricity generated in high-efficiency cogeneration is certified yellow or purple. According to an information of the President of the Energy Regulatory Office No. 22/2014, on the unit charge replacements for existing cogeneration in 2015 the value of purple certificate (Ozm) was determined in the amount of 63.26 PLN/MWh and yellow certificate (Ozg) in the amount of 121,63 PLN/ MWh [14]. Table 4 gives a breakdown of revenues. To the network will be sold surplus electricity, reduced by the losses occurring in the transformer station of 2%. Whereas revenue for certificates of origin are calculated from the total electricity produced.

Table 4. List of revenues

	Energy, MWh/year	Average trading price, PLN/MWh	Revenue, PLN
Sale of surplus electricity	13 104	163,58	2 143 552
Sales of certified green	14 400	162,00	2 332 800
Sales of certified yellow	14 400	121,63	1 751 472
Total			6 227 824

Table 5 shows gross revenues, costs, profit before taxes, net present value, and internal rate of return for all of the scenarios investigated. The economic results follow from technical results. Higher NPV value represents greater economic benefits for the plant. The analysis showed a positive indicator NPV for 15-year operation of the installation, amounting to 14.1 mln PLN. Internal rate of return (IRR) was used as the second determinant of profitability, amounted to 12.48%. Assumes that, if the NPV is greater than zero and the IRR greater than the adopted discount rate is the realization of the project will be profitable. Both of determinants allow to conclude that the investment has benefits and return on investment DPP is in 8 years.

Table 5. Summary of economic results of biogas plant

Costs,	PLN	2 446 000
Revenues,	PLN	6 227 824
Profit before taxes,	PLN	3 781 824
$NPV_{(15)}$,	PLN	14 089 565
IRR,	%	12.48
DPP,	years	8

Income from sales of electricity constitute 34% of all revenues, and 66% are proceeds from the sale of certificates of origin. However, the lack of long-term price guarantees certificates can increases the risk of the project. Because of this, economic analysis may be changed during operation of the plant and presumably, in the worst scenario, the project will start generating losses instead of profits. Undoubtedly, biomass and results from the processing of biogas are a valuable source of electricity and heat. Furthermore they are an alternative to conventional methods, polluting the environment. Biogas production based on raw materials from the sugar industry is one of the directions, from which sugar factory may take when the European Union will abolished the quota system regulating the sugar economy. Such a project can allow for diversification of sources incomes in the agri-food industry and for the development of such areas. Profile of venture fits perfectly with the profile of a plant producing sugar. Moreover the heat produced in the cogeneration unit conducive to reduce the costs of production. It can be developed for the purposes of process in a sugar factory and thus will allow for savings related to the purchase of solid fuels used to produce the heat and electricity.

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