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EVALUATION OF BIOGAS PRODUCTION AND USAGE POTENTIAL

OCENA POTENCJAŁU PRODUKCJI I WYKORZYSTANIA BIOGAZU

Abstract: The aim of the research is the development of theoretical and methodical bases for determining the feasibility of plant raw materials growing for its further bioconversion into energy resources and technological materials to maximize profit from business activities. Monograph, statistics, modelling and abstract logical methods have been used during the research. Directions of biogas usage have been examined. Biogas yields from different crops have been analyzed. It has been determined that high methane yields can be provided from root crops, grain crops, and several green forage plants. So, forage beet and maize can provide more than 5,500 m^3 of biogas per hectare. Attention is paid to the use of by-products of biogas plants, especially carbon dioxide. Carbon dioxide is an important commodity and can increase profitability of biogas plant operating. It can be used for different purposes (food industry, chemical industry, medicine, fumigation, *etc*). The most important parameters of the biogas upgrading technologies have been analyzed. If output of an upgrade module is more than 500 nm^3/h, investment costs of different available technologies are almost equal. According to experts, it is economically feasible to use anaerobic digestion biogas systems to upgrade biomethane provided their performance is equivalent to 3,000 litres of diesel fuel per day. The economic and mathematical models have been suggested to determine the feasibility of growing plant materials to maximize the gross profit. The target function is the maximum gross income from biogas utilization. It has the following limitations: annual production of biogas, consumption of electricity, heat and motor fuels. The mathematical model takes into account both meeting own requirement and selling surplus energy resources and co-products including carbon dioxide. In case of diesel fuel substitution, an ignition dose of diesel fuels has been considered. The algorithm for making a decision on construction of a biogas plant has been offered.

Keywords: biogas, biogas plant, methane, upgrading of biogas, objective function, efficiency, economic and mathematical model, motor fuel, crop, energy resources

Introduction

The efficiency of crop production depends on the market situation. Thus, in Ukraine from 2009 to 2012, the crop production was highly profitable. However, in 2013, there was a collapse in prices for agricultural products. For example, the corn price fell down from

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275 USD/Mg to 150 USD/Mg. It adversely affected the profitability of agricultural producers. Therefore, the market situation requires adopting of it [1].

One of the possible ways to increase economic stability may be growing biomaterial for production of energy resources. Among plant biofuels, biogas has the biggest energy output per unit area. So, biogas is the most promising renewable fuel [2].

Cities and towns produce a lot of industrial and municipal wastes. They can be converted into gaseous fuel - biogas. Besides, biogas can be produced from other sources: landfills, livestock operations, wastewaters, *etc* [3, 4].

Landfills are designated locations for disposal of waste collected from residential, industrial, and commercial entities. Landfills are the third-largest source of human-related methane emissions. Biogas from landfills is also called landfill gas (LFG), as the digestion process takes place in the ground rather than in an anaerobic digester.

Biogas recovery systems at livestock operations can be used to produce renewable natural gas. Animal manure is collected and delivered to an anaerobic digester to stabilize and optimize methane production. The resulting biogas can be processed into renewable natural gas (RNG) and used to fuel natural gas vehicles.

Biogas can be produced during the digestion of solids removed in the wastewater treatment process. Energy generated at U.S. wastewater treatment plants (WWTPs) could potentially meet 12% of the national electricity demand [5].

There are more than 16,000 WWTPs in the United States, and about 1,500 employ anaerobic digestion to produce biogas that is used on site. The Janesville Wastewater Treatment Plant in Wisconsin is an example of a plant that uses biogas to produce RNG for use in vehicles [6].

Other sources of biogas include organic waste from industrial, institutional, and commercial entities, such as food manufacturing and wholesalers, supermarkets, restaurants, hospitals, educational facilities, *etc*. Biogas can also be produced from lignocellulosic material, such as crop residues and dedicated energy crops [7].

Today in the world, significant amounts of biogas are produced at integrated enterprises, mainly cooperatives [8-10]. This is due to the benefits of association which secure significant reduction in costs for the integrated production and, consequently, in enhancing its competitiveness.

Therefore, there is some theoretical and practical interest to study the economic feasibility of using plant bio-material for production of renewable energy [11].

Material and methods

In order to achieve the objective, the authors have analyzed different sources of data. The materials for research include statistical and analytical data which were subject to mathematical and graphic processing. The study data were analyzed by descriptive and quantitative techniques. Economic and mathematical modelling in the study to determine the effectiveness of different pathways of biogas utilization instead crop growing has been used.

Results and discussion

The world experience shows that a significant amount of biogas is produced from plant material. For example, in Austria, there are more than 40 such biogas systems [12]. According to existing studies conducted in the EU, the most efficient feedstock for biogas production is corn silage. This culture possesses the greatest energy efficiency factor - up to 5.1 [13]. Moreover, crops for biogas production can be grown on degraded lands [14].

Most of the conventional agricultural crops are suitable for anaerobic digestion if they are harvested before lignification begins. High methane yields can be achieved by root crops, grain crops, and several green forage plants (Fig. 1) [15].

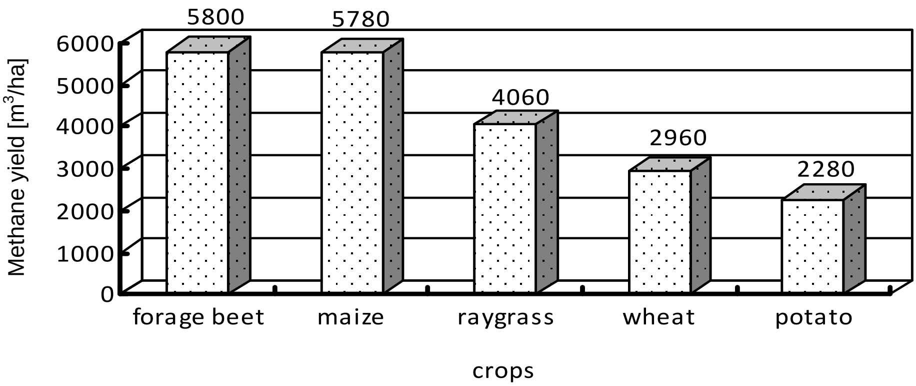

Fig. 1. Methane yield of various crops [15]

The highest methane yields per hectare can be achieved by forage beets, forage maize, and several multiple, cutting green forage plants such as ryegrass, sudan grass, or alfalfa [15].

Scientists studied the effectiveness of power generation from biogas. Extensive scientific research in this direction has been conducted in Germany and other EU countries [15-17]. The scientific problem of efficient production and use of biogas has also been studied by scientists in other countries. The scientific papers are devoted to self-sufficiency of agriculture in energy resources, including biogas, efficiency and biogas potential, technical and economic aspects of biogas production.

Energy efficiency of different biogas systems, including single and co-digestion of multiple feedstock, different biogas utilization pathways, and waste-stream management strategies have been evaluated by Poschl, Ward and Owende [18]. Energy balances are analysed from a life-cycle perspective for biogas systems based on eight different raw materials [19].

But the problem of methodological basis of determining the cost-effectiveness of energy crops for use in biogas plants based on such factors as use of by-products of biogas and biomethane production, direction for further transformation of renewable gaseous fuels compared to the possible benefits of growing other crops remains insufficiently researched [20, 21].

That is why it is important to develop methodical basis for determining feasibility of plant material growing by agricultural producers to bio-convert it into biogas considering its further transformation.

Production of any product is economically feasible, if its gross income is higher in comparison to alternative options. This also applies to growing raw materials to produce biogas for its further transformation.

We have made an assessment of the gross income from the use of biogas. The silage corn and sorghum are mainly used to produce bioenergy. They have yield, respectively, up to 250 and 1000 centners/ha. It allows to get from 6.25 to 13.0 thousand m^3 of biogas from one hectare respectively.

The resulting gaseous biofuels can be used for different purposes: electricity generation, cogeneration, replacement of natural gas and motor fuels. Organic fertilizers and carbon dioxide (resulting in upgrading of biogas) also have market value.

Biogas produced is mainly used for generation of heat and electricity in most countries with the exception of Sweden, where approximately half of produced biogas is used as vehicle fuel. Many countries, such as Denmark, Germany and South Korea, among others, show initiatives and interest in increasing the share of biogas to be used as vehicle fuel in the near future [22].

In Germany (the largest producer of biogas in Europe) according to the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, in 2013 the main part of the biogas was used for electricity and heat production, while biogas utilization as a vehicle fuel is rare (1%) [22].

In 2013 about 170 filling stations with 100% biomethane sold 300 TWh biomethane. This corresponds to 20% of natural gas consumption by 95,000 registered gas vehicles in Germany [22].

Sweden utilizes the most share of biogas as motor fuel. In this country, around 50% of biogas is used as vehicle gas. This part is increasing every year to meet the increasing demand from the increasing number of gas vehicles. The main part of remaining biogas is used for heat production [22].

In Sweden, nearly all upgraded biogas is used as automotive fuel, designated “fordonsgas” (vehicle gas), which means that the annual biomethane production in Sweden is around 900 GWh. The biomethane is produced in 53 biogas upgrading plants with various technologies (~70% water scrubbers and, ~15% PSA, ~15% amine scrubbers). In one plant, with the capacity of 60 GWh, biomethane is liquefied and sold as LBG (LiquefiedBioGas). Of methane used as automotive fuel, the biomethane share was 58% on energy basis in 2013. It is used by 47,000 gas vehicles, of which 2,200 are buses and 750 are heavy duty vehicles. Around 210 filling stations dispense vehicle gas, five of these also have liquid vehicle gas [22].

Sweden has no feed-in tariffs, but instead it uses other support systems, mainly focused on increasing the usage of biomethane as automotive fuel. The existing support systems are: no carbon dioxide or energy tax on biogas until the end of 2015 (Corresponding to around 70 EUR/MWh compared to petrol and 56 EUR/MWh compared to diesel, and of which 24 EUR/MWh is from the carbon dioxide relief and the remaining part is from the energy tax relief); 40% reduction of income tax for use of company NGVs until 2017; investment grants for marketing of new technologies and new solutions for biogas during the period 2010-2016 (maximum 45% or 25 MSEK (~3 M€) of investment cost, *etc*) [22].

So biogas can be used as fuel for natural gas vehicles.

Applications of CO_2 are the following. Carbon dioxide can have mainly two forms - Liquid and Solid. Solid CO_2 is also known as “dry ice” and is used as refrigerants in food industry and for small shipments. CO_2 is widely utilized during the storage and shipping of ice cream and other frozen foods. Some of the CO_2 applications are listed below:

- Fire Extinguishers: CO_2 extinguishes fires. Carbon dioxide extinguishes flames, and some fire extinguishers, especially those designed for electrical fires, contain liquid carbon dioxide under pressure. Carbon dioxide extinguishers work well on small flammable liquid and electrical fires, but not on ordinary combustible fires, because although it excludes oxygen, it does not cool burning substances significantly and when the carbon dioxide disperses they are free to catch fire upon exposure to atmospheric oxygen.

- Beverage: This gas is used to make carbonated soft drinks and soda water. Carbon dioxide is used to produce carbonated soft drinks and soda water. Traditionally, carbonation of beer and sparkling wine came about through natural fermentation, but many manufacturers carbonate these drinks with carbon dioxide recovered from the fermentation process. In the case of bottled and kegged beer, the most common method used is carbonated with recycled carbon dioxide.
- Solvent: Liquid CO_2 is considered as a good dissolving agent for many organic compounds. Here it can be used to remove caffeine from coffee.
- Plants: Plants require CO_2 to execute photosynthesis, and greenhouses can promote plant growth with additional CO_2.
- Pressured Gas: It is used as the cheapest non-combustible pressurized gas. Pressured CO_2 is inside tins in life jackets. Compressed CO_2 gas is used in paintball markers, airguns, for ballooning bicycle tires. Carbon dioxide is also used as an atmosphere for welding, although in the welding arc, it reacts to oxidize most metals.
- Medicine: In medicine, up to 5% CO_2 is added to pure oxygen. This helps in provoking breathing and to stabilize the O_2/CO_2 balance in blood.
- CO_2 Laser: The CO_2 laser, a common type of industrial gas laser uses CO_2 as a medium.
- Welding: It also finds its use as an atmosphere for welding.
- Oil Wells: Carbon dioxide is commonly injected into or next to producing oil wells to draw lost traces of crude oil.
- Chemical Industry: It is used as a raw material in the chemical process industry, especially for urea and methanol production.
- Metals Industry: It is used in the manufacture of casting influences so as to enhance their hardness.
- Fumigation: Carbon dioxide is used as a fumigant to increase shelf life and remove infestations.
- Wine making: Carbon dioxide in the form of dry ice is often used in the wine making process to cool down bunches of grapes quickly after picking to help prevent spontaneous fermentation by wild yeast.
- Refrigerant: Comparison of phase diagrams of carbon dioxide (red) and water (blue) as a log-lin chart with phase transition points at 1 atmosphere. Liquid and solid carbon dioxide are important refrigerants, especially in the food industry, where they are employed during transportation and storage of ice cream and other frozen foods. Its physical properties are highly favorable for cooling, refrigeration, and heating purposes, having a high volumetric cooling capacity. Coca-Cola has fielded CO_2-based beverage coolers and the U.S. Army is interested in CO_2 refrigeration and heating technology [23, 24].

So carbon dioxide is a costly commodity and can increase profitability of biogas plant using. In Ukraine the cost of compressed carbon dioxide is around 1.96 USD/nm^3. It is much more than natural gas price [25].

Currently, a number of different technologies for the major biogas upgrading step are commercially available. This major step comprises drying of raw biogas and removal of carbon dioxide, and thus the enhancement of the heating value of the final gas produced. These proven technologies will be presented in the following section. The removal of minor or trace components from raw biogas will be discussed subsequently. Typically, these removal steps are already included in any commercially available biogas upgrading plant.

It is hard to give a universally valid comparison of different biogas upgrading technologies because many essential parameters strongly depend on local circumstances. Furthermore, the technical possibilities of a certain technology (for example, regarding the quality of achievable biomethane) often do not correspond with the economic efficiency [21].

Table 1, summarizes the most important parameters of the described biogas upgrading technologies applied to a typical raw biogas composition. Values of certain parameters represent averages of realized upgrading plants or verified data from literature. The price basis used is from March 2012 [26].

Table 1

Parameters of upgrading technologies [26]

Parameter	**Water scrubbing**	**Organic physical scrubbing**	**Amine scrubbing**	**PSA**	**Membrane technology**
typical methane content in biomethane [vol.%]	95-99	95-99	> 99	95-99	95-99
methane recovery [%]	98	96	99.96	98	80-99.5
methane slip [%]	2.0	4.0	0.04	2.0	20-0.5
typical delivery pressure [MPa]	0.4-0.8	0.4-0.8	0	0.4-0.7	0.4-0.7
electric energy demand [kWh/m^3 biomethane]	0.46	0.49-0.67	0.27	0.46	0.25-0.43
heating demand and temperature level	-	medium 70-80°C	high 120-160°C	-	-
desulphurisation requirements	process dependent	yes	yes	yes	yes
consumables demand	antifouling agent, drying agent	organic solvent (non-hazardous)	amine solution (hazardous, corrosive)	activated carbon (non-hazardous)	
partial load range [%]	50-100	50-100	50-100	85-115	50-105
number of reference plants	high	low	medium	high	low
typical investment costs [€/(m^3/h) biomethane] for 100 m^3/h biomethane	10,100	9,500	9,500	10,400	7,300-7,600
for 250 m^3/h biomethane	5,500	5,000	5,000	5,400	4,700-4,900
for 500 m^3/h biomethane	3,500	3,500	3,500	3,700	3,500-3,700
typical operational costs [ct/m^3 biomethane] for 100 m^3/h biomethane	14.0	13.8	14.4	12.8	10.8-15.8
for 250 m^3/h biomethane	10.3	10.2	12.0	10.1	7.7-11.6
for 500 m^3/h biomethane	9.1	9.0	11.2	9.2	6.5-10.1

Some experts in Canada and the USA suggest that it is economically feasible to install an anaerobic digestion system and upgrade to biomethane provided they produce enough to feed the equivalent of a 500 kW generator, or 3,000 diesel dm^3 equivalents per day. This expenditure results in fuel cost that is lower in cost than diesel or gasoline, factoring in a 10-year return on investment, excluding the cost of vehicle conversion. Note there are separate costs for AD equipment, biomethane upgrading equipment, and compression and injection equipment. Key technical considerations for consumers relate to converting vehicles, compressing and storing biomethane, and refueling [27].

As a vehicle fuel, it is shown that biomethane generates the greatest amount of vehicle fuel energy for a given amount of raw material, making it environmentally preferable to biodiesel or ethanol. Biomethane has the same energy content as conventional natural gas, since both energy sources are comprised of methane (Fig. 2) [28, 29].

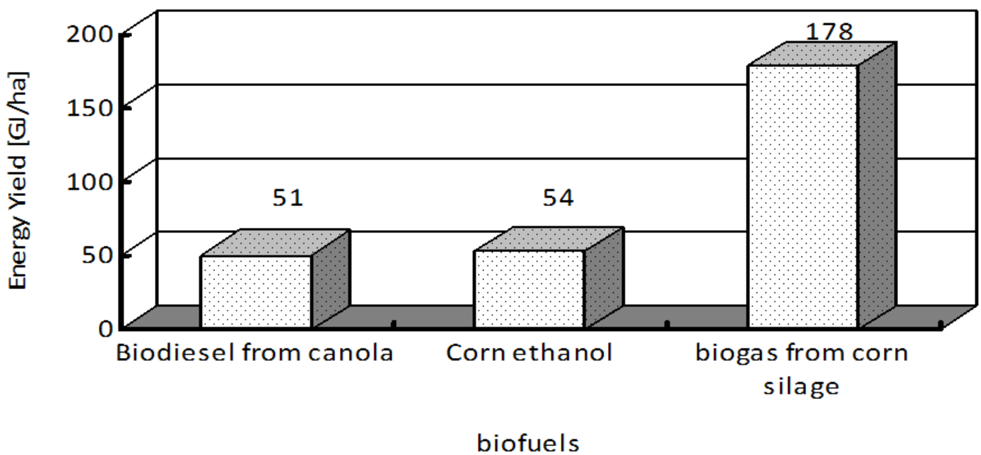

Fig. 2. Energy yield from different biofuel crops [28, 29]

Material and energy flows of biogas plant are shown in Figure 3. If we use a municipal or/and industrial waste, the scheme of material and energy flows will have somewhat different appearance (Fig. 4).

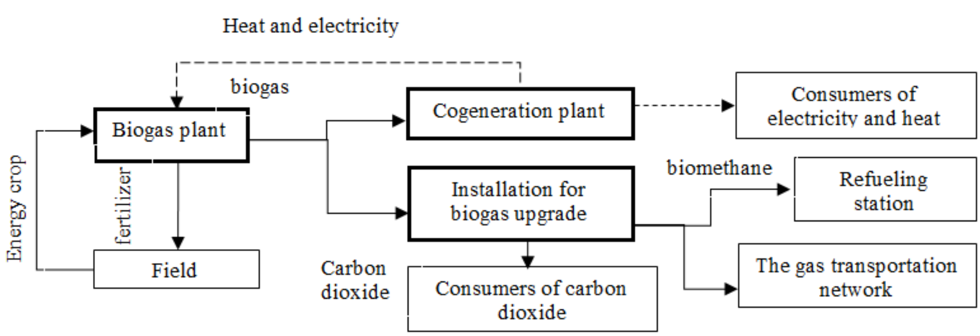

Fig. 3. Material and energy flows of biogas plant

The maximum gross income of energy resources and additional products received per unit area in the prices of December 2013, are shown in Figure 5. In comparison with 2012, the income of vegetable production (corn) amounted 5500 USD per hectare, which is less than the potential income from the use of biogas derived from plant material.

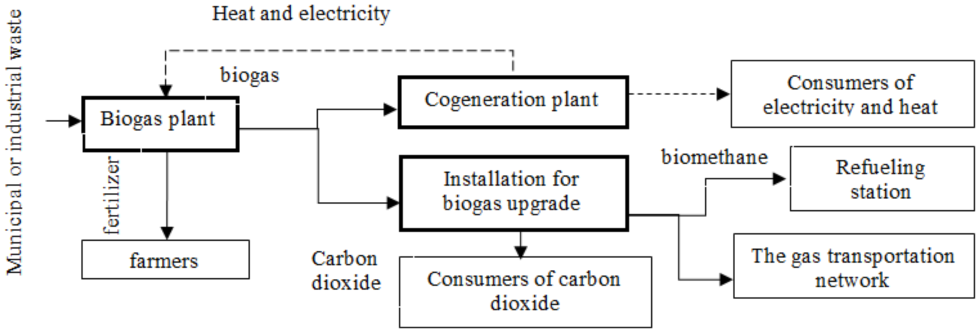

Fig. 4. Material and energy flows of a biogas plant using municipal or/and industrial waste

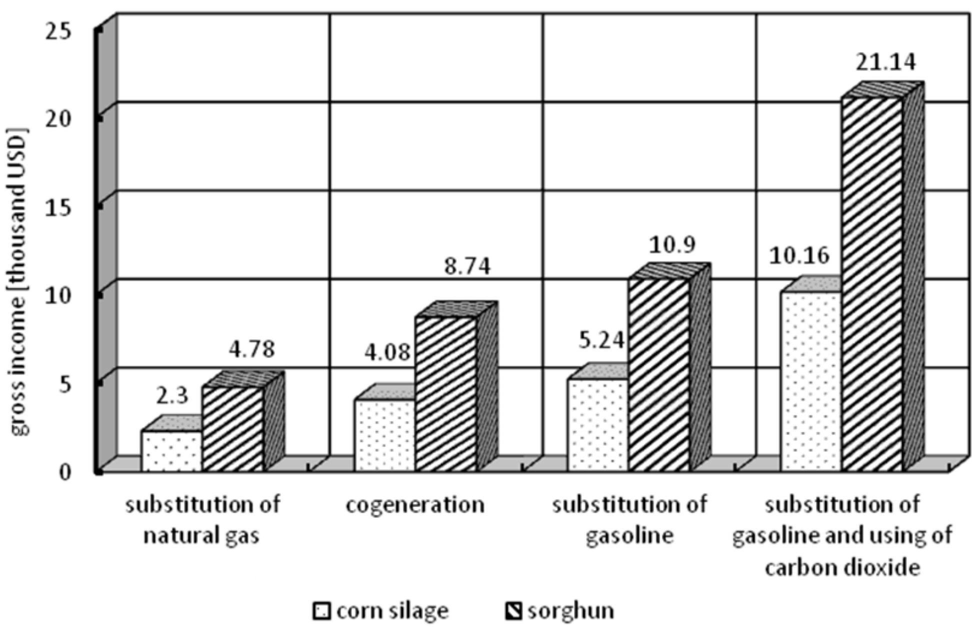

Fig. 5. A gross income per hectare in some variants of using biogas

Cultivation and use an energy crop in a biogas plant is appropriate if the gross profit from the use of biogas and by-products exceeds the gross income from growing crops. As a criterion of efficiency of growing energy crop, we suggest using the ratio of the gross income, respectively, from the operation of a biogas plant and growing crops. Let us consider the proposed objective function in the following formula

$$K = \frac{GI - OC}{SAGI} \rightarrow \max \quad (1)$$

where GI is the gross income from the use of biogas and by-products [USD/ha]; OC - operational expenditure of a biogas plant [USD/ha]; $SAGI$ - the specific average gross income from crops growing [USD/ha].

If $K > 1$, than growing of energy crop for use as a substrate is economically feasible.

Specific average gross profit (per hectare) of crops growing can be determined by the formula

$$SAGI = \frac{\sum_{i=1}^{n} \left[F_i \cdot U_i \cdot \left(P_i - C_i \right) \right]}{\sum_{i=1}^{n} F_i} \text{ [USD/ha]} \tag{2}$$

where F_i is area of i^{th} crop cultivation [ha]; U_i - yield of i^{th} crop [Mg/ha]; P_i - market price of i^{th} crop [USD/Mg]; C_i - production cost of i^{th} crop [USD/Mg]; n - number of crops.

The volume of biogas per unit area is determined by the formula

$$V = \alpha \cdot U \text{ [m}^3\text{/ha]} \tag{3}$$

where α is biogas yield [m^3/Mg]; U - energy crop yield [Mg/ha].

A gross income from the use of energy crop or other substrate in a biogas plant can be determined by the following formula

$$GI = Ee + Em + En + Ecd + Ema \tag{4}$$

where Ee, Em, En, Ecd, Ema are a gross income from production of electrical energy; thermal energy; substitution of conventional motor fuels; use of carbon dioxide and manure [USD].

Let us consider the gross income from operation of a biogas plant. The gross income from the use of electricity is equal to

$$Ee = \begin{cases} \left(\dfrac{x_1 + x_2}{be_e} - We_o \right) \cdot Pe & at\ \dfrac{x_1 + x_2}{be_e} \le We_o + We_f \\ We_f \cdot Pe + \left[\dfrac{x_1 + x_2}{be_e} - We_o - We_f \right] \cdot Pe_o & at\ \dfrac{x_1 + x_2}{be_e} \ge We_o + We_f \end{cases} \tag{5}$$

where be_e is specific biogas consumption in electric generator [m^3/(kWh)]; We_o, We_f - annual demand in electric power by a biogas plant and an agrarian and industrial enterprise [kWh]; Pe_o - wholesale price of electricity [USD/(kWh)]; Pe - retail price of electricity [USD/(kWh)]; x_1 - annual consumption of biogas by an engine-generator plant [nm^3]; x_2 - annual consumption of biogas by a co-generation plant [nm^3].

The use of heat energy can give such an income

$$Em = \begin{cases} 0 & at\ \dfrac{x_1}{be_h} + \dfrac{x_3}{be_b} \le Qe_o \\ \left[\left(\dfrac{x_1}{be_h} - Qe_o \right) \cdot \dfrac{T_0}{365} - \dfrac{x_3}{be_b} \right] \cdot Pm & at\ Qe_o \le \dfrac{x_1}{be_h} + \dfrac{x_3}{be_b} < Qe_o + Qe_f \end{cases} \tag{6}$$

where T_0 is duration of a heat season of an enterprise per year [days]; be_h - specific biogas consumption for heat production in a cogeneration plant [m^3/(kWh)]; be_b - specific biogas consumption for heat production in a boiler [m^3/(kWh)]; Qe_f - annual demand for thermal energy of an agrarian and industrial enterprise [kWh]; Qe_o - annual demand in thermal energy of a biogas plant [kWh]; Pm - the price of thermal energy [USD/(kWh)]; x_3 - annual consumption of biogas by a boiler [nm^3].

Biogas or biomethane may be used to substitute conventional motor fuel (diesel fuel) and bring in income

$$En = \frac{x_4 \cdot Q_b}{\rho \cdot Q_d} \cdot Pn, \tag{7}$$

where ρ is density of diesel fuel, ρ = 0,83…0.87 kg/dm^3; Q_b - lower heating value of biogas [MJ/m^3]; Q_d - lower heating value of diesel fuel [MJ/kg]; Pn - the price of diesel fuel [USD/dm^3]; x_4 - annual consumption of biogas by vehicles [nm^3].

The deficit of electricity and thermal energy for provision of a biogas plant can be determined by the formula

$$W = \begin{cases} 0 & at\ \frac{x_1}{be} + \frac{x_2}{be} \geq Ne_o \\ We_0 - \left(\frac{x_1}{be} + \frac{x_2}{be}\right) & at\ \frac{x_1}{be} + \frac{x_2}{be} < Ne_o, \end{cases} \tag{8}$$

and

$$Q = \begin{cases} 0 & at\ \frac{x_1}{be_h} + \frac{x_3}{be_b} \geq Qe_o \\ Qe_0 - \left(\frac{x_1}{be_h} + \frac{x_2}{be_b}\right) & at\ \frac{x_1}{be_h} + \frac{x_3}{be_b} < Qe_o. \end{cases} \tag{9}$$

If biogas is upgraded (to use as motor fuel), in addition, we can get and use carbon dioxide as a product. In this case, the gross profit will be equal to

$$Ecd = \varphi \cdot x_4 \cdot Pcd \tag{10}$$

where φ is carbon dioxide content in biogas; Pcd - the price of carbon dioxide [USD/m^3].

The objective function has limiting parameters. The volume of annual biogas using is restricted by condition

$$\sum_{i=1}^{n} x_i \leq V \tag{11}$$

where V is annual production of biogas by a biogas plant [m^3].

The volumes of thermal energy that can be produced are limited by two factors. The first is that there are restrictions on its use for the needs of a biogas plant and enterprise - one’s owner

$$\left(\frac{x_1 \cdot T_0}{365 \cdot be_h} + \frac{x_2}{be_b}\right) \leq Qe_0 + Qe_f \tag{12}$$

There is another limitation. The daily use of biogas should not exceed biogas plant productivity. This condition has the following mathematical record

$$V \geq x_1 + x_2 + x_3 \cdot \frac{365}{T_0} \quad (13)$$

Here, we do not consider simultaneous use of biogas to provide an agricultural and industrial enterprise with thermal energy and to substitute conventional motor fuel with biogas, as they do not coincide in time.

The restrictions on the substitution of conventional motor fuel (diesel fuel), which an enterprise uses, also has two components. The first one is that it is the maximum need for gaseous fuels

$$x_4 \leq (1 - \lambda) \cdot Md \cdot \frac{Q_b}{Q_d}, \quad (14)$$

where λ is a dose of diesel fuel to ignite biogas (biomethane) and air mixture (when running on diesel and gas cycle); Md - annual demand in diesel fuel [kg].

The second one takes into account the duration and simultaneity of agricultural machinery work with different consumers of biogas and limited by daily productivity of a biogas plant

$$V \geq x_1 + x_2 + x_4 \cdot \frac{365}{T_0} \quad (15)$$

where T_0 is annual duration of use of agricultural machinery [days].

Specific expenditure (per hectare) for growing energy crops and a biogas plant operating BC

$$BE = U \cdot Ce + \frac{U}{M} \cdot \left\{ Wg + W \cdot Pe + Q \cdot Pm + DE + 0.01 \cdot \sum_{j=1}^{m} \left(a_j + a_{pj}\right) \cdot K_j \right\} \quad (17)$$

where Ce is production cost of energy crop [USD/Mg]; M - annual consumption of substrate by a biogas plant [Mg]; a_j, a_{pj} - depreciation and overhaul of j^{th} type of equipment; K_j - price of j^{th} type of equipment [USD]; Pe - price of electrical energy [USD/(kWh)]; Pm - price of thermal energy [USD/(kWh)]; Wg - wage [USD]; DE - other expenses [USD].

Table 2

Gross profit from the use of biogas to a gross income from growing crops ratio

Item	**Biogas capacity [nm^3/h]**			
	250	**500**	**1000**	**2000**
Investment [mln EUR]	4.17	6.13	9.1	13.61
Land area for maize silage [ha]	619	1238	2475	4950
Criteria *K*				
Co-generation	2.94	4.00	4.67	5.09
Compressed natural gas	1.72	2.00	2.15	2.22
Diesel	3.42	3.71	3.85	3.92
Compressed natural gas + carbon dioxide	6.41	6.70	6.84	6.91
Diesel + carbon dioxide	8.11	8.40	8.54	8.62

Let us consider examples of the feasibility study for construction of biomethane plants based on maize silage instead crops growing. A water scrubber technology is selected as a method of biogas upgrading. There are five variants of biomethane utilization: co-generation (green tariff); substitute of compressed natural gas for vehicles; displacement of diesel fuel; substitute of compressed natural gas for vehicles and carbon dioxide using; displacement of diesel fuel and carbon dioxide using. The base for study is developments of the Bioenergy Association of Ukraine. According to our calculations, the scale of the project has a significant impact on economic performance. Utilization of carbon dioxide increases efficiency considerably (Table 2).

For the co-generation it is necessary to highlight that it is difficult to get green tariff. Moreover, utilization of heat is limited. That is why efficiency of co-generation, in actual practice, will be less.

The following algorithm for making a decision on the construction of a biogas plant is offered:

Step 1. Determination of initial data: area of agricultural land; cropping pattern; dynamics of crop yields and production costs; market prices; the necessary amount of energy resources to meet requirement of a biogas plant; the necessary amount of energy resources to meet the requirements of an enterprise - a biogas plant's owner; the potential market of energy resources and by-products of a biogas plant.

Step 2. Determining the maximum permissible area of land for energy crops to meet the needs of an agrarian and industrial enterprise in energy resources, market potential; agro-technical requirements.

Step 3. Selection of equipment for a biogas plant. Evaluation of efficiency of various biogas utilization pathway. Determination of technical and economic indicators.

Step 4. Determining feasibility of energy crops usage for biogas production. General conclusion.

Conclusions

The pathways of biogas usage have been examined. It has been determined that carbon dioxide utilization increases profitability of biogas plant. The studies have shown that growing of energy crops for biogas production can provide significantly greater gross income in comparison with cultivation of traditional crops. A mathematical model to determine the feasibility of energy crops utilization at a biogas plant has been suggested. It takes into account costs of energy resources, substitution of conventional motor fuels, utilization of electricity and heat, as well as use of carbon dioxide.

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