DETERMINING IMPACT OF DIFFERENCE IN PRICE OF LIQUID MANURE AND DEGESTATE ON PRODUCTION COSTS OF BIOMETHANE AND ELECTRICITY

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Abstract. Assessment of production costs to get biomethane and electric power on its basis in agriculture is impossible without assessing the impact on this indicator of the price of digestate. In Ukraine, where chernozem soils are the basis of agricultural production, the issue of restoring their fertility is an urgent problem. The production of biomethane should take into account the costs of manure before fermentation and the sales revenue of digestate after fermentation using it as organic fertilizers. The article suggests a methodology for economic assessing of production costs to get biomethane and electric power on its basis provided that the costs for the production of biomethane include production costs with taking into account the difference in prices of the biomass of liquid manure before fermentation in the digester and digestate after fermentation in the digester. The technique is based on the calculation of such indicators as a requirement in biomass to receive one m^3 of biomethane and to get one kW hour of electricity. These values for liquid manure in accordance are 93.3 $kg \cdot m^{-3}$ and 23.9 $kg \cdot kWh^{-1}$. The zero production costs of biomethane and biomethane-based electricity production will be when the price of digestate will be more than the price of liquid manure before fermentation in the range from 1.1 to 2.0 $EUR \cdot t^{-1}$. The zero-profit of biomethane production will be when the price of digestate will be less than the price of liquid manure before fermentation in the range from 1.3 to 2.1 $EUR \cdot t^{-1}$. The zero-profit of electricity production will be when the price of digestate will be less than the price of liquid manure before fermentation in the range from 4.1 to 6.6 $EUR \cdot t^{-1}$. The suggested methodology may be useful for the assessment of production costs when carrying out measures for the utilization of digestate and in the training process of biotechnologists.

Keywords: liquid manure, digestate, biomethane, biogas plant, digester.

Introduction

Biomethane production is one of the alternative types of receiving energy in the agrarian production and product processing fields. In Ukraine, there are biogas plants with a total capacity of 47 MW using agricultural biomass. Various organic raw materials are used as raw material to produce biomethane with different degrees of production costs. These are, for example, stems of cereals and legumes, waste from alcohol, wine production [1; 2], and oil crop processing [3], etc. The use of biomethane to generate electricity makes it possible to improve the environmental situation and reduce dependence on external energy supplies [4]. However, a common problem with biogas plants is the difficulty of the utilization of the digester.

Animal manure is considered the best raw material for biogas production, but manure is also one of the best organic fertilizers. Therefore, it is important to justify the choice of manure as a raw material for receiving biogas or usage as organic fertilizers. Paper [5] presents the studies on the prediction of biogas production from the manure of different animals, taking into account the accessibility factor, which also includes the use of manure as an organic fertilizer, but the methodology for determining this factor is not revealed.

A large number of experimental studies have now been conducted on the yield of biogas and biomethane during anaerobic digestion [6; 7]. In most cases of anaerobic digestion of manure and plant biomass the level of decomposition of organic biomass over time can be approximated by an exponential relationship. In the analysis of experimental results it was found that the value of the maximum level of decomposition of organic biomass is in the range of 0.45 to 0.59 rel. un. and depends on the type of biomass. An algorithm for calculating the specific yield of biogas and biomethane during anaerobic fermentation and biogas reactor operation in the periodic loading mode was developed to determine the integral rate and level of organic biomass decomposition. The application of the algorithm for calculating the specific yield of biogas and biomethane during anaerobic fermentation of manure showed that at the density of biogas under normal conditions 1.2 $kg \cdot m^{-3}$ the output of biogas and biomethane in the biogas plant will be respectively 1.3 $m^3 \cdot m^{-3}$ and 0.91 $m^3 \cdot m^{-3}$ biomass per day, that corresponds to the performance of existing plants [8].

Two approaches are considered classic in determining the economic efficiency of biogas and fertilizer production. According to the first one, the normative value of the percentage rate of profit which should provide an income sufficient for expanded capital reproduction was taken into account, the second one includes the price of biomethane at the market price of natural gas, and the price of solid and liquid fertilizers according to the formula: normative prime costs + 50% [9-11]. In addition, the assessment of the economic efficiency of biomethane production and electricity based on it in agricultural enterprises traditionally includes production expenses for biomethane production and capital costs for equipment construction.

Ferrari G.et al. conducted a thorough analysis of research in the field of biogas production and focused on the need to develop innovative mathematical models to develop decision-making tools that can more accurately model future development scenarios for both bioenergy in general and biogas technologies [12].

Usually, digestate must be accumulated, as its use is prohibited in winter, impossible in summer due to the vegetation in the fields, and in spring it is often impractical due to high soil moisture. This requires additional buildings, which increases the cost of digestate utilization and leads to additional problems. There are often cases of neglect of environmentally friendly digestate utilization for profit.

However, at present, there are no fast methods for the economic assessment of biomethane production and biomethane-based electricity with using simple and clear production indicators.

The purpose of the study was to propose a methodology for assessing production costs to get biomethane and biomethane-based electricity on its basis in agriculture, provided that the costs for biomethane production in agricultural enterprises include production costs for receiving biomethane minus the excess value of digestate price after fermentation in a digester over the price of manure before fermentation.

Materials and methods

The production costs of biomethane and biomethane-based electricity production were determined taking into account the difference between the price of digestate and the price of liquid manure before fermentation. Two options were considered: biomethane production and biomethane-based electricity generation. Then the obtained values of production costs were divided by the volume of produced biomethane and biomethane-based electricity. The number of deductions for maintenance and repair of the biogas plant, costs of electricity consumed for the production, and wages fund with social charges for personnel of the biogas plant were considered. The production costs as sum fixed costs and the difference between the price of digestate and the price of liquid manure before fermentation were determined at different possible values. The obtained values of production costs were compared with the price of natural gas and the green tariff for electricity.

Based on this comparison it is possible to make a conclusion about the potential profitability and unprofitability of the biogas plant and to analyze the potential profitability of improving the methods of utilization of digestate.

Results and discussion

It is well known that the costs for biomethane production in agricultural enterprises include production costs for receiving biomethane minus the excess value in the price of digestate after fermentation in a digester over the price of manure and the expenses for biomethane-based electricity production includes production costs for receiving electricity minus the excess value in the price of digestate after fermentation in a digester over the price of manure:

$$\begin{aligned} B_{BM} &= V_{BM}C_{BM} = m_{LM}C_{LM} - m_{LM}\left(1-k_F\right)C_{OF} + E_{PBM}; \\ B_{EL} &= W_{EL}C_{EL} = m_{LM}C_{LM} - m_{LM}\left(1-k_F\right)C_{OF} + E_{PEL}. \end{aligned} \tag{1}$$

The production costs of biomethane production and of electricity production based on biomethane are:

$$
\begin{aligned}
C_{BM} &= \frac{m_{LM}}{V_{BM}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{BM} = \frac{V_{PB}\rho_{PB}}{V_{BM}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{BM} = \\
&= 365\frac{V_P\rho_{PB}}{V_{BM}\tau_{FT}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{BM} = \frac{\rho_{PB}}{k_{BM}\tau_{FT}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{BM}; \\
C_{EL} &= \frac{m_{LM}}{W_{EL}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{EL} = \frac{V_{PB}\rho_{PB}}{W_{EL}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{EL} = \\
&= 365\frac{V_P\rho_{PB}}{W_{EL}\tau_{FT}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{EL} = 365\frac{3.6V_P\rho_{PB}}{V_{BM}q_{BM}\eta_G\tau_{FT}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{EL} = \\
&= \frac{3.6\rho_{PB}}{k_{BM}q_{BM}\eta_G\tau_{FT}}\left[C_{LM}-\left(1-k_F\right)C_{OF}\right]+E_{EL}.
\end{aligned}
\tag{2}
$$

The excess value in the price of digestate over the price of manure to ensure zero production costs of biomethane and of electricity will be:

$$
\begin{aligned}
\left(1-k_F\right)C_{OF}-C_{LM} &= \frac{E_{BM}k_{BM}\tau_{FT}}{\rho_{PB}}; \\
\left(1-k_F\right)C_{OF}-C_{LM} &= \frac{E_{EL}k_{BM}q_{BM}\eta_G\tau_{FT}}{3.6\rho_{PB}}.
\end{aligned}
\tag{3}
$$

Or taking into account depreciation expense:

$$
\begin{aligned}
\left(1-k_F\right)C_{OF}-C_{LM} &= \frac{\left(E_{BM}+A_{BM}\right)\,k_{BM}\tau_{BM}}{\rho_{PB}}; \\
\left(1-k_F\right)C_{OF}-C_{LM} &= \frac{\left(E_{EL}+A_{EL}\right)k_{BM}q_{BM}\eta_G\tau_{FT}}{3.6\rho_{PB}},
\end{aligned}
\tag{4}
$$

where B_{BM} – general production costs for biomethane production, EUR;
B_{EL} – general production costs for biomethane-based electricity production, EUR;
V_{BM} – volume of received biomethane, m^3;
W_{EL} – amount of produced electricity, kWh;
C_{BM} – production costs of biomethane, EUR·m^{-3};
C_{EL} – production costs of electricity, EUR·kWh^{-1};
m_{LM} – mass of liquid manure taking for the fermentation, t;
k_F – coefficient of the reduction of biomass in the digester during fermentation, relative units;
C_{LM} – average price of liquid manure, EUR·t^{-1};
C_{OF} – average price of digestate, EUR·t^{-1};
E_{PBM} – production expenses for biomethane production excluding the cost of liquid manure and digestate, EUR;
E_{PEL} – production expenses for producing electricity based on biomethane excluding the price of liquid manure and digestate, EUR·kWh^{-1};
E_{BM} – specific production expenses for biomethane production, EUR·m^{-3};
E_{EL} – specific production expenses for biomethane-based electricity production, EUR·kWh $^{-1}$;
V_{PB} – volume of processed biomass in the digester, m^3;
ρ_{PB} – density of processed biomass in the digester, t·m^{-3};
V_P – volume of biomass in the digester, m^3;
k_{BM} – biomethane output per day from the volume unit of the digester, m^3·m^{-3} per day;
τ_{FT} – time of biomass keeping in the reactor during fermentation, days;
q_{BM} – heat-forming capacity of biomethane, MJ·m^{-3};
η_G – efficiency factor of a diesel-generator when receiving electricity, relative units;
3.6 – conversion factor, MJ·kWh^{-1};
A_{BM} – depreciation expense for biomethane production, EUR·m^{-3};

A_{EL} – depreciation expense for biomethane-based electricity production, EUR·kWh^{-1}.

Further detailing of expression (2), by revealing the structure of specific production expenses for biomethane production and for biomethane-based electricity production, allows us to write down:

$$C_{BM} = \frac{\rho_{PB}}{k_{BM}\tau_{FT}}\left(C_{LM} - C_{OF}\right) + \left(1 + k_{TE} + k_{GEE}\right)\ \left(MAR_{BM} + EL_{BM} + S_{BM}\right);$$
$$C_{EL} = \frac{3,6\rho_{PB}}{k_{BM}q_{BM}\eta_G\tau_{FT}}\left(C_{LM} - C_{OF}\right) + \left(1 + k_{TE} + k_{GEE}\right)\left(MAR_{EL} + EL_{EL} + S_{EL}\right), \quad (5)$$

where k_{TE} – coefficient that takes into account the general production expenses, relative units;
k_{GEE} – coefficient that takes into account the general economic expenses, relative units;
MAR_{BM} – deductions for maintenance and repair of a biogas plant for biomethane production, EUR·m^{-3};
MAR_{EL} – deductions for maintenance and repair of biogas plant for electricity production, EUR·kWh^{-1};
EL_{BM} – costs of electricity consumed for biomethane production, EUR·m^{-3};
EL_{EL} – costs of electricity consumed in the production of electricity based on biomethane, EUR·kWh^{-1};
S_{BM} – wages fund with social charges in biomethane production, EUR·m^{-3};
S_{EL} – wages fund with social charges in biomethane-based electricity production, EUR·kWh^{-1}.

Technological and economic initial data for the calculation of production costs of biomethane production and biomethane-based electricity production in the case of anaerobic fermentation of cattle and pig manure are given in Table 1.

Table 1

Technological and economic initial data for calculation of the production cost indexes of biomethane production

Index		Symbol	Value
Density of biomass with humidity of 92% for processing in the digester, t·m^{-3}		ρ_{PB}	1.05
Biomethane output per day from the volume unit of the digester, m^3·m^{-3} day	min	k_{BM}	0.75
	max		1.2
Time of biomass keeping in the reactor during fermentation, days		τ_{FT}	15
Need in biomass for receiving 1 m^3 of biomethane during fermentation		$\frac{\rho_{PB}}{k_{BM}\tau_{FT}}$	0.0933 t·m^{-3}
Heat-forming capacity of biomethane, MJ·m^{-3}		q_{BM}	37
Efficiency factor of a diesel-generator when receiving electricity, relative units		η_G	0.38
Need in biomass for receiving 1 kWh of electricity during fermentation		$\frac{3.6\rho_{PB}}{k_{BM}q_{BM}\eta_G\tau_{FT}}$	0.0239 t·kWh^{-1}
Coefficient that takes into account the general production costs, relative units		k_{TE}	0.05
Coefficient that takes into account the general economic costs, relative units		k_{GEE}	0.1
Deductions for maintenance and repair of biogas plant, EUR·m^{-3}		MAR_{BM}	0.05
Costs of electricity consumed for production, EUR·m^{-3}		EL_{BM}	0.015
Wages fund with social charges for personnel, EUR·m^{-3}		S_{BM}	0.011
Deductions for maintenance and repair of biogas plant, EUR·kWh^{-1}		MAR_{EL}	0.013
Costs of electricity consumed for the production, EUR·kWh^{-1}		EL_{EL}	0.004
Wages fund with social charges for personnel, EUR·kWh^{-1}		S_{EL}	0.003

Now, a large number of studies have been conducted to determine the amount of biogas and the content of biomethane in it that can be obtained during anaerobic fermentation of various types of biomass [13]. The value of

$$\frac{\rho_{PB}}{k_{BM}\tau_{FT}}$$

is the inverse of the amount of biomethane that can be obtained per unit biomass during anaerobic digestion. The value of

$$\frac{3.6\rho_{PB}}{k_{BM}q_{BM}\eta_G\tau_{FT}}$$

is the inverse of the amount of electricity that can be obtained per unit biomass during anaerobic digestion. These unique values are easily determined on the basis of biogas plant production indicators, and the presence of values of fixed costs of the biogas plant and the difference in prices for liquid manure and digestate allow to predict the profitability of biomethane and biomethane-based electricity.

The data of modeling the production costs of biomethane production and biomethane-based electricity production depending on the difference between the prices of liquid manure biomass before fermentation in the digester and digestate after fermentation are presented in Fig. 1.

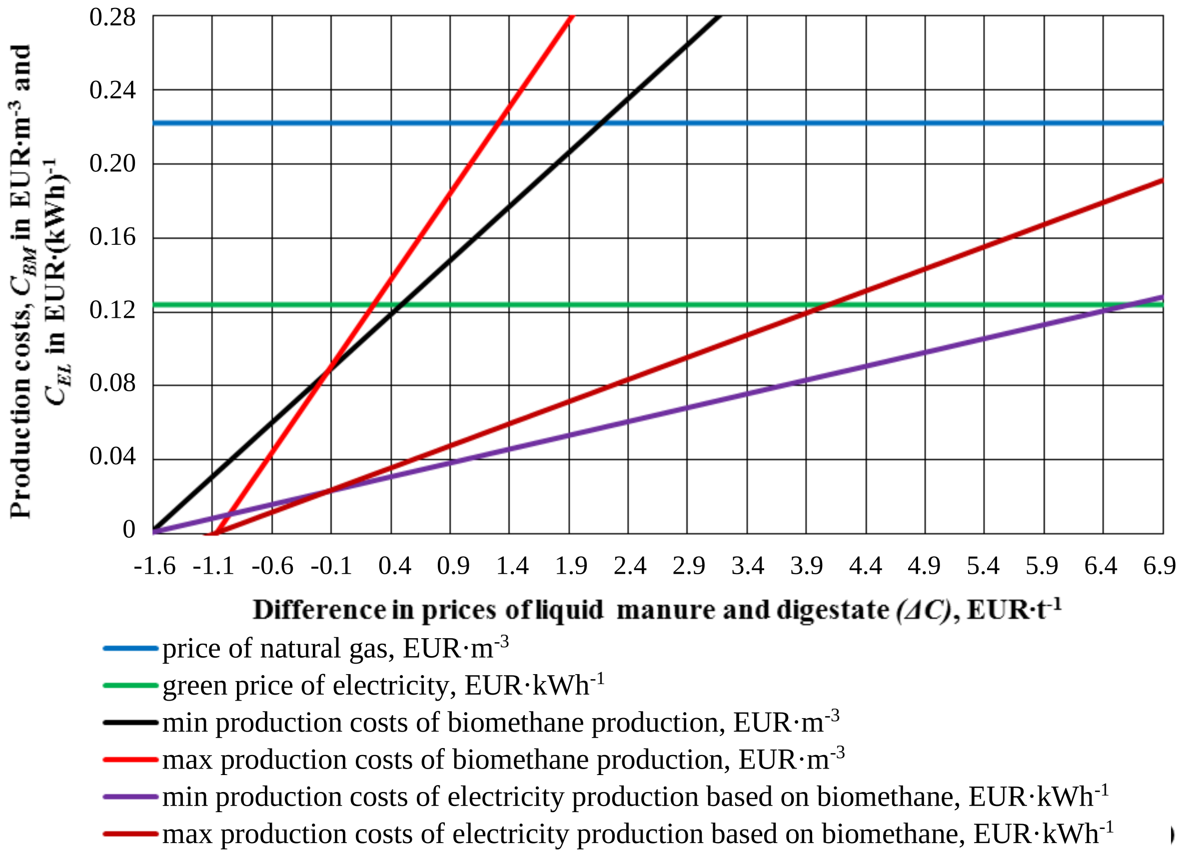

Fig. 1. **Calculation of the production costs of biomethane production and biomethane-based electricity production when the price of digestate after fermentation C_{OF} = 3.4 EUR·t^{-1} and k_F = 0.04**

Conclusions

The difference between the price of digestate and the price of liquid manure before fermentation and a requirement in biomass to receive one m^3 of biomethane and to get one kW hour of electricity play an important role in estimating the production costs of biomethane production and biomethane-based electricity production. It is known that the biogas yield per day from the volume unit of the digester is in the range from 1.0 to 1.7 m^3·m^{-3} a day. In this case, the zero production costs of biomethane and biomethane-based electricity production will be when the price of digestate will be more than the price of liquid manure before fermentation in the range from 1.1 to 2.0 EUR·t^{-1}. In addition, the zero-profit of biomethane production will be when the price of digestate will be less than the price of liquid manure before fermentation in the range from 1.3 to 2.1 EUR·t^{-1}. The zero-profit of electricity production will be when the price of digestate will be less than the price of liquid manure before fermentation in the range from 4.1 to 6.6 EUR·t^{-1}. The suggested methodology may be useful for the economic assessment of production costs when carrying out measures for the utilization of digestate and in the training process of biotechnologists.

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