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Perspectives for biogas generation from manure on the farms in the Leningrad Region of the Russian Federation

E. Timofeev* and A. Erk

Federal State Budgetary Scientific Institution 'Federal Scientific Agroengineering Center VIM', branch in Saint Petersburg, Filtrovskoje shosse, 3 p.o. Tiarlevo, RU 196625 Saint Petersburg, Russia
*Correspondence: timofeev_ev84@mail.ru

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Abstract. The interest in biogas in the Leningrad Region is consistently growing. Biogas can replace fossil fuels in different applications and reduce greenhouse gas emissions. The study aimed to demonstrate the perspectives for its generation from livestock waste and further farm application. The farm energy audits identified the pattern of fuel and energy consumption. Computational and statistical methods were applied to estimate the biogas generation. First, the study considered a cattle farm with 1,800 head and manure output of 43,300 t year^{-1}. According to calculations, the farm can fully meet its own needs for electricity or motor fuel by converting the manure into biogas. Meanwhile, the fuel use of biogas can reduce pollutant emissions by almost 30% against conventional fuel. Secondly, the study estimated the biogas production potential from the farm organic waste in the whole Leningrad Region with the total cattle stock of 165,000 head, pig stock of 184,000 head, and poultry stock of 29,180,000 head, producing about 8 million t year^{-1} of animal/poultry manure. According to calculations, the livestock waste processing will yield up to 500 million m^3 of biogas. This is enough to fully cover the energy inputs of the farms in this region. However, the payback period for biogas plants is above eight years. The positive aspects of biogas application are introducing biogas in the farm energy balance as an energy resource; reducing the hazardous emissions owing to the improved processing of organic farm waste; obtaining high-quality fertilisers to consequently increase crop yields.

Key words: biogas, electrical power, manure, motor fuel.

INTRODUCTION

The Leningrad Region specialises in animal husbandry, which accounts for 68% of the gross output. Dairy farming is the main branch; poultry farming consistently achieves high outputs over the years, and pig farming also shows good promise. The Leningrad Region currently has a total stock of about 165,000 head of cattle, 184,000 head of pigs, and 29,180,000 head of poultry (Petrostat, 2020).

Alternative energy gathers pace these days that is closely associated with changing the vector of government policy.

Biogas as a renewable energy source can be used for different purposes - to generate electricity and heat, or biofuel (biomethane or biodiesel) (Ardebili & Khademalrasoul, 2018). Biogas can replace fossil fuels in different applications and, consequently, reduce greenhouse gas emissions. The farms can apply the energy generated from biogas for their own needs. Biogas can be injected into a natural gas pipeline after CO_2 removal. The gas pipeline network can also be used in the construction of biogas filling stations. If there is no the gas pipeline network near the biogas plant, then a biomethane filling station can be built next to the biogas plant (On-farm Biogas Production, 2013).

Since 1990, the European Union, the United States and other countries adopt the official guidelines for introduction of renewables, with biogas being one of them.

In 2009, the European Union adopted the Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Directive, 2009) and then proposed the 2030 Climate & Energy Framework, which aims at least 32% share for renewable energy (2030 Climate & Energy Framework, 2014), with the fuel from biomass playing an important role. Since 1995, the number of biogas plants in the EU countries increased from several dozen pieces to almost 20,000 pieces (Fücks, 2013; European Union Renewable Energy Handbook, 2016).

In Germany alone, more than 9,000 biogas plants are in operation (Thrän et al., 2020). The EU envisages raising the biogas production by 10% annually. Each EU country has a construction programme of biogas plants (Nurmet, et al., 2019.

Even northern countries, such as Finland, are targeted for an increase from 200 units in 2020 to 5,000 units by 2050, thus providing the full self-sufficiency in motor fuel. Concurrently, regulations are adopted on the introduction of gas-driven vehicles (Latvala, 2009; On-farm Biogas Production, 2013; Kymäläinen & Pakarinen, 2015; Nylund et al., 2015; Gasum, 2019).

Besides, increasingly restrictive emission regulations concerning cars and vehicles appear every year with the ultimate target for reducing greenhouse gas emissions and obtaining ‘zero’ emissions from fuels.

In Russia, the biogas history started in the 1980s following the USSR Government Decree on the production of biogas from organic agricultural waste, sewage and solid household waste. Experiments were undertaken and experimental equipment was manufactured. However, biogas turned out to be nearly five-fold more expensive than natural gas and its production never became widespread. The current biogas industry has around 20 biogas plants in the Belgorod, Moscow and Leningrad Regions. Nevertheless, the RF Ministry of Energy and the Ministry of Industry and Trade plan to increase their number to 100 pieces in the next three years. The overall raw material resources for biogas plants, agricultural waste, mostly, are estimated as 81 million tons of reference fuel. If these resources are recycled, they will provide up to 23% of the total inputs of electricity, up to 15% of heat energy and up to 15% of fuel for motor vehicles (European Union Renewable Energy Handbook. 2016).

The biogas production technology from the ready biomass is based on the stimulation of natural processes. Optimal conditions should be created for manure bacteria for rapid multiplication and efficient digestion of substances. For this purpose, the biological raw material is placed in an oxygen-tight tank. After that, anaerobic microbes convert phosphorus, potassium and nitrogen-containing compounds into pure forms. The result is both biogas and high-quality fertilisers, which are well suited for agricultural application and are more efficient than traditional manure (Krištof & Gaduš, 2018; Mainardis, 2019).

Biogas production from poultry manure involves the anaerobic decomposition of manure, purification of resulting biogas and combustion in gas reciprocating engines to generate electricity and thermal energy by utilising heat from engine exhaust gases. The cogeneration complex based on a biogas plant produces up to 90 m^3 of the biogas per one ton of anaerobically decomposed poultry bedding manure with 60% moisture content (Gasum, 2019). Low heating value of biogas is 20.93–27.21 MJ $(Nm^3)^{-1}$; the electrical efficiency of gas reciprocating engines is 35%; the operation of gas reciprocating engines allows to obtain up to 40% of the initial energy fuel potential in the form of thermal energy (Kymäläinen & Pakarinen, 2015).

The purpose of the study was to demonstrate the estimated potential of biogas generation from manure on livestock farms in the Leningrad Region. The novelty of the study was the feasibility assessment of including biogas in the farm energy balance as an energy resource.

MATERIALS AND METHODS

The energy audits revealed the pattern of fuel and energy consumption on the farms in the Leningrad Region. Both computational and statistical research methods were applied to estimate the biogas generation.

The amount of organic material in the manure produced was calculated according to (Latvala, 2009; Ganieva et al., 2011; Mamontov, 2016) by formula (1):

$$V_{OM} = m \cdot k \cdot \varphi_{org} \qquad (1)$$

where V_{OM} – volume of manure organic matter produced per year, t; m – the mass of initial raw material, t; k – portion of dry matter content; φ_{org} – portion of organic matter in dry material.

Methane production from liquid manure per cow per year is calculated by the formula (2):

$$V_{meth} = V_{OM} \cdot y_{biogas} \cdot f_{meth} \qquad (2)$$

where V_{meth} – volume of methane produced, m^3; y_{biogas^s} – specific biogas output per one ton; f_{meth} – methane content in the biogas (Latvala, 2009; Ganieva et al., 2011; Mamontov, 2016).

CO_2 equivalent from combustion of motor fuel was calculated using the Methodology for calculating greenhouse gas emissions (CO_2-equivalent) (Methodology, 2015; Usenko et al., 2016).

CO_2 equivalent from combustion of biogas-based motor fuel was calculated using the methodology from (Moiseev, 2015).

The first part of the study was to estimate the biogas generation on a dairy farm in the Leningrad Region with the cattle stock of 1,800 head and manure output of 43,300 t $year^{-1}$. Generation and use of biogas were calculated under the following assumptions: a dairy cow produces about 66 kg of liquid manure per day, or about 24,000 t $year^{-1}$ under the housing conditions in the Leningrad Region (Bryukhanov & Shalavina, 2015). In the liquid manure the dry matter content is 10% and the organic matter content is about 80% (Mamontov, 2016; Gasum, 2019).

The second part of the study was to estimate the biogas generation at the level of the Leningrad Region.

RESULTS AND DISCUSSION

The amount of organic material in the manure produced on the selected dairy farm was $V_{OM} = 24 \cdot 0.1 \cdot 0.8 = 1{,}920$ t per cow.

The specific biogas output per one ton of dry organic matter from liquid manure was 360 m^3 with 60% methane content (Mamontov, 2016).

This way, the selected dairy farm produced

$V_{meth} = 1.92 \cdot 360 \cdot 0.6 = 414.7$ m^3 of methane per cow per year.

Since 1 m^3 of methane contains approximately the same amount of energy as 1 liter of diesel fuel, that is 10 kWh, the energy savings by the produced biogas will be about 4,147 kWh per cow per year.

Table 1 shows the actual energy consumption on the farm in 2019.

Table 1. Actual consumption of considered energy resources on the farm in 2019

Indicator	Actual consumption		
	Natural units		Money terms, thousand RUR
Electrical energy	thousand kWh	2,504	10,878
Motor fuel	t	720	15,780

The data in Table 1 were used for forecasting the energy consumption when using a biogas plant on the selected farm. The calculations were based on the above methods.

Table 2 shows the calculated forecast of energy consumption if the selected farm with 1,800 cows uses a biogas plant with 35% efficiency.

Table 2. The calculated forecast of energy consumption if the selected farm uses a biogas plant

Indicator	Actual consumption	
	Biogas plant output	Farm's demand
Electrical energy, thousand kWh	2,612	2,504
Biogas-based motor fuel, t	756	720

From Table 2, a biogas plant using manure of the farm cows can fully meet the farm needs in electricity and motor fuel.

Fig. 1 shows a graph comparing the energy consumption and its generation with the use of a biogas plant on the selected farm by months.

The electrical energy produced on the biogas plant was different every month since it depended on the average monthly temperatures and on its consumption to maintain the anaerobic digestion at the biogas plant.

The calculations show that, in general, the selected farm may obtain the required electrical energy with the help of animal waste produced.

The calculated data analysis shows that the farm can fully satisfy its own needs in electricity or motor fuel by processing manure produced into the biogas. The savings in the first case will be 11 million RUR $year^{-1}$; in the second case - 16 million RUR $year^{-1}$. However, it should be borne in mind that the cost of a biogas plant of such capacity is 120–180 million RUR and the payback period is above eight years. This way, the calculation of savings only in terms of fuel and energy generation shows a lack of profitability.

At the same time, the additional useful features of biogas plants might be reasonable to consider – production of high-quality organic fertilisers and a significant reduction in pollutant emissions when generating energy from biogas.

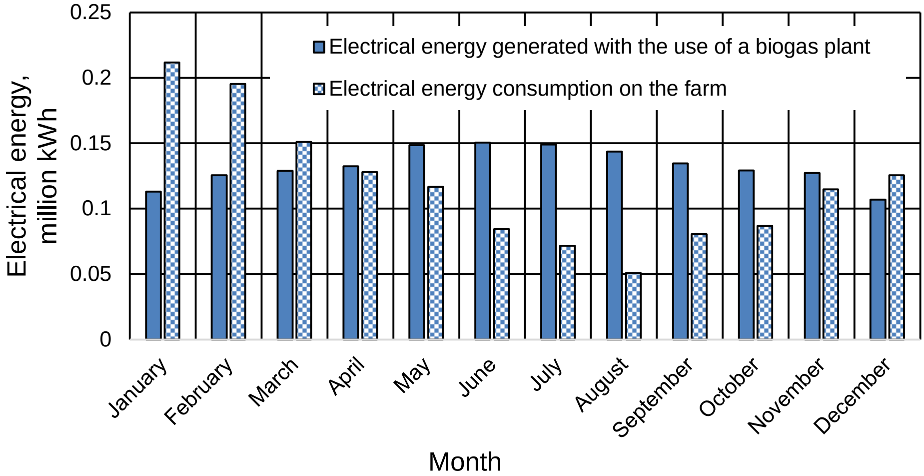

Figure 1. Analysis of the energy balance of the selected farm with the use of biogas.

The fuel application of biogas was calculated to reduce emissions by almost 30% compared to conventional fuel. The mathematical method of regression analysis established that the reduction effect increased every year. An approximating function was obtained:

$$y = 7065.3x^2 + 33199x + 1E{+}06 \quad R^2 = 0.8927$$

This function quite accurately describes the change in emissions over the years. It allows predicting the CO_2 equivalent emissions on the farm and taking relevant measures to mitigate the anthropogenic pressure on the environment.

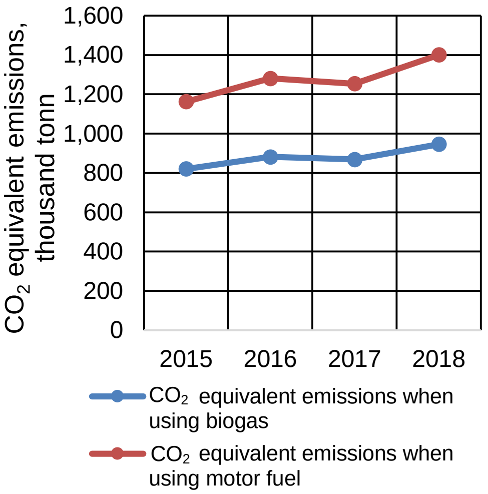

Figure 2. Dynamics of changes in CO_2 equivalent emissions when using traditional fuel and biogas.

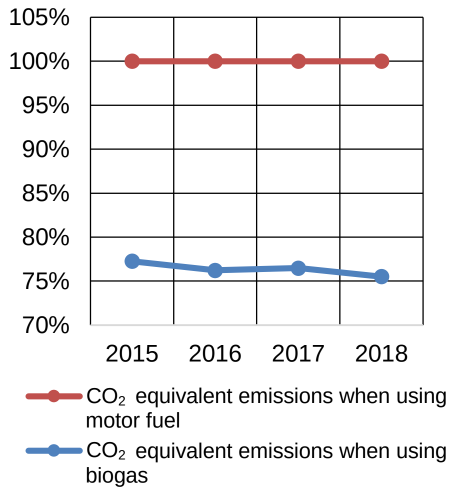

Figure 3. Dynamics of reduction of CO_2 equivalent emissions when using biogas.

The use of biogas would allow the selected farm to reduce pollutant emissions by 22–25%. This indicator is a significant argument in favour of switching to biogas.

The second part of the study was to estimate the biogas generation at the regional level.

According to the energy surveys, on dairy, beef and pig farms the electrical energy inputs account for 55% of the total energy consumption, motor fuel inputs - for 30–40% and heat and gas inputs - for 5–15%. On poultry factories, the gas inputs account for 58% of the total energy consumption if they have gas boiler houses in place, electrical energy inputs - for 30% and motor fuel inputs - for 12% (Sudachenko et al., 2017a).

Large-scale agricultural enterprises are the main producers of livestock and poultry products, and also manure (Table 3).

Table 3. Total amount of manure produced on cattle, pig and poultry complexes in the Leningrad Region, t year^{-1}

Type of manure	Cattle	Pigs	Poultry	Total
Solid	2,116,051	-	1,242,545	3,358,596.0
Semi-liquid and liquid	4,029,902	581,696.2	-	4,611,598.2
Total	6,145,953	581,696.2	1,242,545	7,970,194.2

From Table 3, the total manure output in the region is about 8 million t year^{-1}. The most efficient manure management on large-scale agricultural enterprises is the key task of modern agroecology (Bryukhanov & Shalavina, 2015; Vasilev, 2015; Bryukhanov et al., 2017).

Poultry manure is the most valuable source of biogas, with the output being 100 (m^3) t^{-1} of raw material; pig manure holds the second place in this respect with the output of up to 75 (m^3) t^{-1}, and cattle manure is in the third place with the output of up to 55 (m^3) t^{-1} (Ermilova & Redina, 2018; Krištof & Gaduš, 2018).

Fig. 4 shows the estimated potential for biogas production from organic waste (all types of manure) from all livestock farms in the Leningrad Region.

The potential biogas generation from the livestock farm organic waste in the Leningrad Region was estimated in up to 500 million m^3.

From Fig. 4, the cattle waste has the biggest promise on the regional level yielding above 300 million m^3 of gas per year.

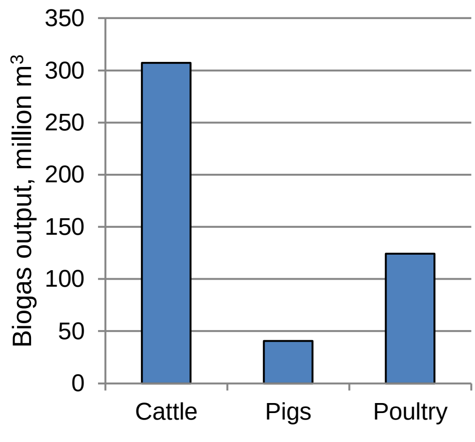

Figure 4. Estimated potential of producing biogas from organic waste (all types of manure) from all livestock farms in the Leningrad Region.

According to technical and economic calculations, the payback of biogas plants in the Leningrad Region would be above eight years (Sudachenko et al., 2017b). Therefore, they are not profitable today in terms of electrical energy generation.

It is advisable, however, to consider the additional strong points of biogas plants - resulting high-quality organic fertilisers and a significant reduction in pollutant emissions in generating energy from biogas.

At the same time, the introduction of gas fuel will decrease carbon dioxide emissions. Fig. 5 shows the forecast for biogas replacing motor fuel in agriculture. The calculation is based on motor fuel consumption in the agro-industrial complex in 2019 and the forecast of the Ministry of Economic Development until 2050 (Energy strategy, 2020).

From Fig. 5, replacing motor fuel with biogas will reduce emissions by 32% by 2050. Besides, the yearly increase in gas and electricity costs promotes the wider introduction of biogas projects. In this context, the livestock farms will be able to provide themselves with energy resources and fertilisers, which ultimately will ensure the competitiveness of agri-products.

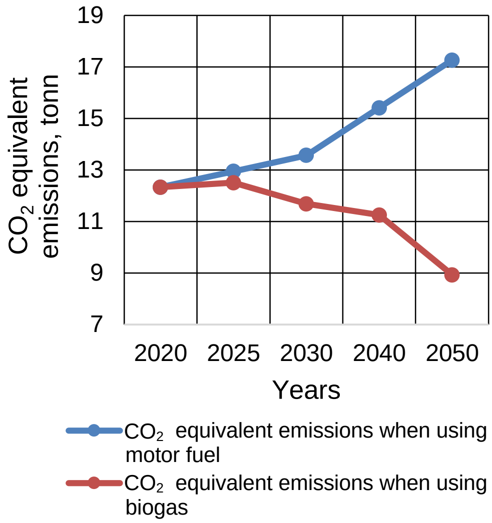

Figure 5. Forecast of carbon dioxide emissions reduction when biogas replaces motor fuel in agriculture.

CONCLUSIONS

The analysis of perspectives for the use of biogas produced from organic animal waste was undertaken for a selected farm with a cattle stock of 1,800 head and a manure output of 43,300 t year^{-1}. The study calculations demonstrated that the farm, can fully satisfy its own need for electricity or motor fuel by processing the manure produced into biogas. The savings in the first case will be 11 million RUR year^{-1}, in the second - 16 million RUR year^{-1}. The use of biogas would allow the selected farm to reduce pollutant emissions in the range of 22–25%. This indicator is a significant argument in favor of switching to energy resources based on biogas.

The estimated potential for biogas production from 8 million t year^{-1} of manure produced in the Leningrad Region with the total about 165,000 cattle head, 184,000 pig head, and 29,180,000 poultry head is up to 500 million m^3.

As calculated for the conditions of the Leningrad Region, one ton of organic dry matter from liquid manure can yield 360 m^3 of biogas with 60% methane content. One cubic meter of methane contains about 10 kWh of energy. Therefore, theoretically, cattle farms only can produce 13,275 thousand MWh that would be enough to fully cover the energy inputs of the farms in the region.

One way to boost the biogas generation and agricultural application is to create large inter-farm complexes with the output of high-quality fertilisers, heat, electricity and gas engine fuel for farms, rural residential buildings and biogas plants proper.

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