FINANCIAL TOOLS FOR BIOGAS PROJECT IMPLEMENTATION AT WASTEWATER TREATMENT PLANTS: A CASE STUDY OF THE RUSSIAN FEDERATION

ANDREY KISELEV & ELENA MAGARIL
Department of Environmental Economics, Ural Federal University, Russian Federation

ABSTRACT
Biogas projects have been recognized as one of the most efficient tools for implementing the principles of circular economy at wastewater treatment plants: negative environmental waste impact reduction along with the energy independence. These projects are widespread in developed countries, but its distribution in developing countries such as the Russian Federation leaves much to be desired. The article discusses the four financial instruments for implementation of biogas projects in the Russian Federation compared to developed countries, including the analysis of sectoral background, potential benefits, drivers and limitation. The authors concluded that barriers for the development of biogas projects are not directly related to the tool entity or its application: significant moral and physical deterioration of technological process line makes the use of these tools untimely, while the long-term payback period leads towards poor efficiency.
Keywords: circular economy, anaerobic digestion, wastewater treatment plants, financial tools, investing.

1 INTRODUCTION

Nowadays environmental situation is keenly exacerbated, due to increased anthropogenic load, exceeding the ability of the biosphere to support the process of self-regeneration. This crisis is a consequence of the practice of human consumer's behavior towards natural environment [1]. Increasing trend of global temperature growth caused by human activities via carbon and other greenhouse gases emissions gives rise to environmental instability and climate change [2].

Wastewater treatment plants (WWTPs) have been recognized as one of the significant greenhouse gases (GHG) generators, due to the complex biochemical reaction and huge consumption of energy and materials [3]. Nowadays, sustainable environmental and energy management has become significant issue in wastewater treatment sector [4]. Anaerobic digestion (AD) is well established and recognized as a robust technology to convert biomass and organic wastes to green energy and fertilizer [5] with an outstanding GHG trapping effect.

Projects based on AD techniques (so-called biogas projects) are widespread in developed countries, in contrast to developing ones. The main reason is not only the availability of modern technologies, but also the additional benefits that are realized in ensuring the energy independence of a particular country by creating a renewable energy source. It has a double profit in terms of high-energy costs in, for example, EU countries, compared to such developing countries as Russian Federation.

The key question is how to promote the circular economy principles by introducing the biogas projects in Russian Federation. It is required to consider possible financial tools of implementing the biogas projects. However, before discussing the financial tools, it is necessary to determine the main goal and specific features of these projects.

AD of sewage sludge is a treatment technique, which is designed for ensuring environmental efficiency in the management of the industrial waste. When sewage sludge is

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disposed of in the special landfill, the organic part of it is being fermented with the release of biogas into the atmosphere, which consist of various pollutants, including carbon dioxide and methane. Both substances are greenhouse gases, but methane has a 21 times stronger effect, compared to the former one. The greenhouse effect leads towards a climate change, an increase in the frequency and scale of natural disasters, and ultimately negatively affects the habitat of humans and animals. Therefore, the capture of biogas is the most effective process to prevent the greenhouse gases from entering the atmosphere and their negative impact, which ultimately increases environmental safety in a particular area.

The biogas, obtained through anaerobic digestion process, is a valuable energy resource that can be used in various ways: to produce thermal energy in boilers, to co-generate heat and electricity in combined heat and power units, or to enrich it into biomethane for further import into the national gas transmission system.

On the other hand, biogas can be used for resource recovery through the extraction of the useful substances, such as carbon dioxide, which can be used in the chemical industry, metallurgy, food industry or elsewhere.

In terms of the sanitary and epidemiological situation, digested sewage sludge becomes stabilized: within the mesophilic mode of AD, the number of pathogens in sewage sludge is significantly reduced, while thermophilic mode of AD makes sewage sludge completely safe. The sewage sludge after AD can be used as organic fertilizer, but the application of this resource in the vast majority of areas is limited due to the presence of heavy metals [6].

The European Union adopted the Sewage Sludge Directive 86/278/EEC in 1986 and the Council Directive 91/271/EEC on urban wastewater treatment in 1991, which led towards the increase of sewage sludge disposal rates and encouraged the usage of sewage sludge in agriculture [1]. The Eurostat reports the data [7] about the agriculture use of sewage sludge as the share of total sewage sludge production. The several leaders for sewage sludge production in 2019 are presented in Table 1.

Table 1: The share of agriculture use for some EU countries in 2019 [7].

EU member	**Year**	**Total production (1,000 tons)**	**Agriculture use (1,000 tons)**	**Share (%)**
Germany	2019	1749.86	287.48	16.43
Spain*	2018	1210.40	1052.70	86.97
France**	2019	1174.00	299.00	25.47
Poland	2019	574.64	123.78	21.54
Netherlands*	2018	341.03	0.00	0.00
Austria	2019	233.56	49.70	21.28
Romania	2019	230.59	43.56	18.89
Hungary	2019	227.89	43.77	19.21
Czechia	2019	221.09	114.31	51.70
Sweden*	2018	211.60	82.30	38.89
Slovakia	2019	54.83	0.00	0.00

According to [8], in the Russian Federation, only 5%–7% of originated sewage sludge is used as a fertilizer. The share of use is negligible due to the insufficient introduction of technologies to prepare for use in agriculture. The adoption of the Federal Law of Russian Federation No. 221-FZ of June 28, 2021 "On Amendments to Certain Legislative Acts of the Russian Federation" clarified the concept of the term "agrochemicals": peat, animal and crop

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production waste, sludge and sewage sludge used for the production of organic and organo-mineral fertilizers were excluded from its definition [9]. It is expected that the legislative initiative will expand the opportunities for using sewage sludge as a fertilizer.

The implementation of biogas projects grants one more advantage for the company – the creation of positive company's image (or prestige). Despite the fact that this feature is quite difficult for assessment, it certainly affects many of the economic, social and manufacturing characteristics of the company.

The benefits summary for biogas project implementation is presented in Fig. 1.

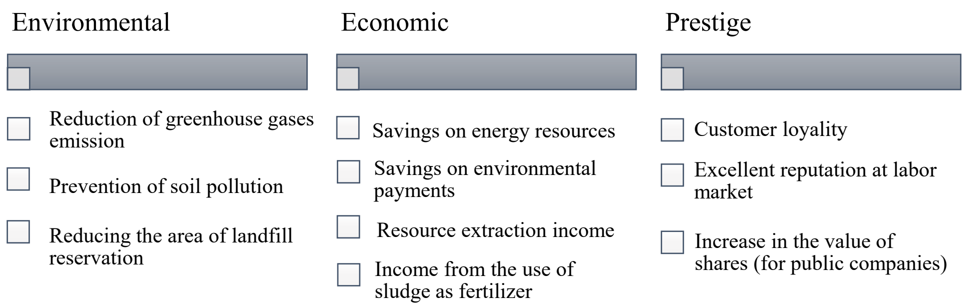

Figure 1: Benefits summary for biogas project implementation.

The cost of biogas project implementation is quite significant while companies, which operate WWTP, do not have sufficient investment resources.

There are a number of studies towards the implementation of biogas technologies, their economic and environmental efficiency in the context of the transition towards sustainable development and circular economy in developed countries. However, despite the obvious advantages of biogas technologies, the feasibility of their implementation in terms of the return of investment (ROI) in Russian Federation remains uncovered. The technology of biogas yield through AD can become a niche and image building for companies as the obtained benefits do not cover (do not pay off) the invested funds.

This article discusses possible ways to finance biogas projects, with definition of the optimal tool, in the context of the feasibility of applying it to WWTPs in Russian Federation.

2 MATERIALS AND METHODS

2.1 Anaerobic digestion and combined heat and power technology

The principal technological process scheme for WWTP is presented in Fig. 2.

Wastewaters are collected from residential, commercial and industrial buildings through sewerage system and enter the receiving chamber of WWTP. Wastewaters pass through mechanical and biological treatment including solids sedimentation phase, removal of biodegradable organic matter via biochemical oxidation phase and finally go through chemical oxidation (e.g. chlorine treatment). The purified water is discharged into the water bodies, while solid, semi-solid and liquid waste is retained, concentrated and formed into sewage sludge. The originated sewage sludge is treated at mechanical dewatering workshop and then utilized at landfills [10]–[14]. The potential place for biogas projects is marked on the scheme in Fig. 2.

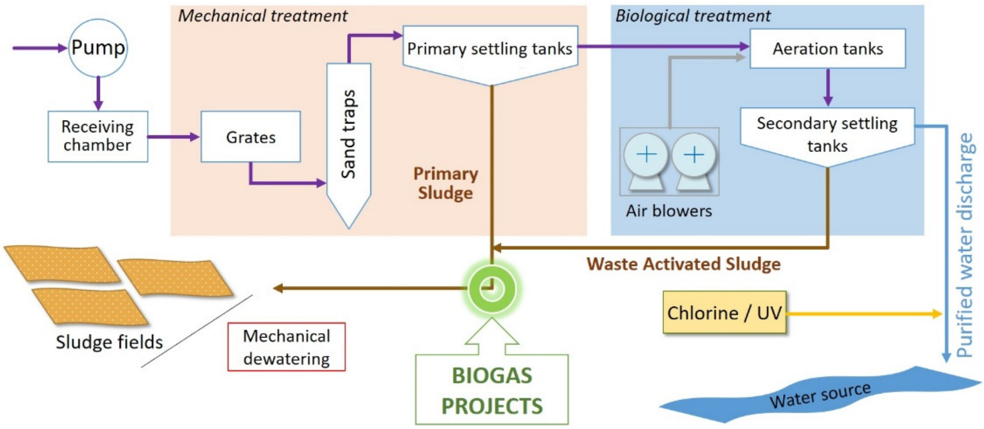

Figure 2: WWTP technological process scheme.

Anaerobic digestion is one of the most popular and widely spread environmental friendly techniques for various organic waste, including sewage sludge. In the absence of oxygen, the organic fraction of sewage sludge is degraded by microbes into biogas, which mainly consists of methane (CH_4) and carbon dioxide (CO_2) [15]–[18]. Biogas can be used directly in combined heat and power (CHP) units, burned to produce heat, or can be enriched and used in the same way as natural gas or as fuel for vehicles. The digested sewage sludge contains nitrogen, phosphorus, potassium etc. and can be applied directly or through composting as fertilizer [19], [20].

The typical technological process of anaerobic digestion is presented in Fig. 3.

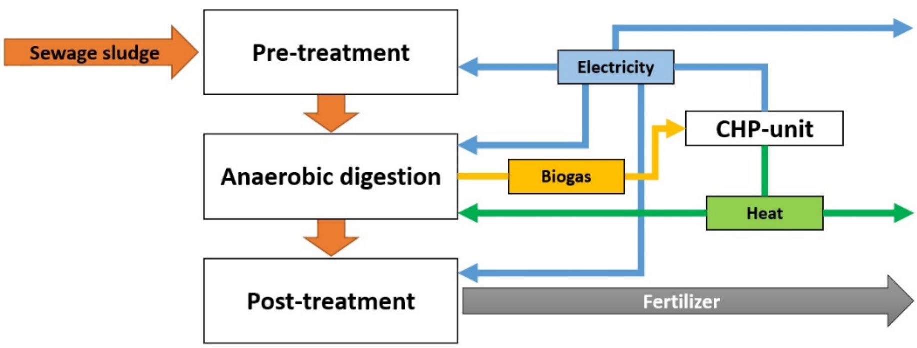

Figure 3: Typical technological process of anaerobic digestion. *(Source: Prepared by authors using data from [20].)*

The digestion process can be wet or dry, mesophilic or thermophilic, and single or multistage. A pre-treatment stage creates opportunities for improvement of biodegradability of sewage sludge through the application of different methods, including biological (e.g. bacteria or enzymes use), mechanical (e.g. ultrasonic, microwave), chemical (e.g. acids) and thermal (e.g. liquid hot water) methods. Pre-treatment improves the overall digestion process's velocity, efficiency, and sludge reduction, thereby reducing the anaerobic digester retention time and increasing the methane production rates [21], [23].

Digested sewage sludge rarely meets the discharge standards and therefore requires post-treatment. For example, digested effluent can be combined with other waste materials such as wood chip, straw or green wastes prior to composting to provide a pasteurized product – this is the best way to improve ecological safety and make valuable fertilizer. In addition, a significant amount of produced methane remains dissolved in the effluents – it can be recovered by special post-treatment techniques [22]–[25].

2.2 Case study area

Ekaterinburg is the fourth largest city in Russian Federation with the population of 1.5 billion inhabitants. It is situated on the border of Europe and Asia and located 1,667 km to the east of Moscow [26]. The centralized sewerage system of Ekaterinburg consists of two main sewerage basins: the northern and the southern. The last outpost of wastewater coming from Northern and Northeastern part of the city is the Northern wastewater treatment plant (WWTP), located in one of the industrial zones of the city. The maximum performance of the Northern WWTP is 100,000 m^3 per day.

The technological process of wastewater treatment at Northern WWTP includes primary (mechanical) and secondary (biological) treatment with ultraviolet disinfection before the discharge of treated wastewater into water bodies. Sludge treatment consists of pumping, thickening and homogenizing primary sludge and waste activated sludge, followed by anaerobic digestion in two concrete digesters, each with a volume of 5,000 m^3 (see Fig. 4), and mechanical dewatering via chamber filter press [27]. Every day almost 370 ton of the

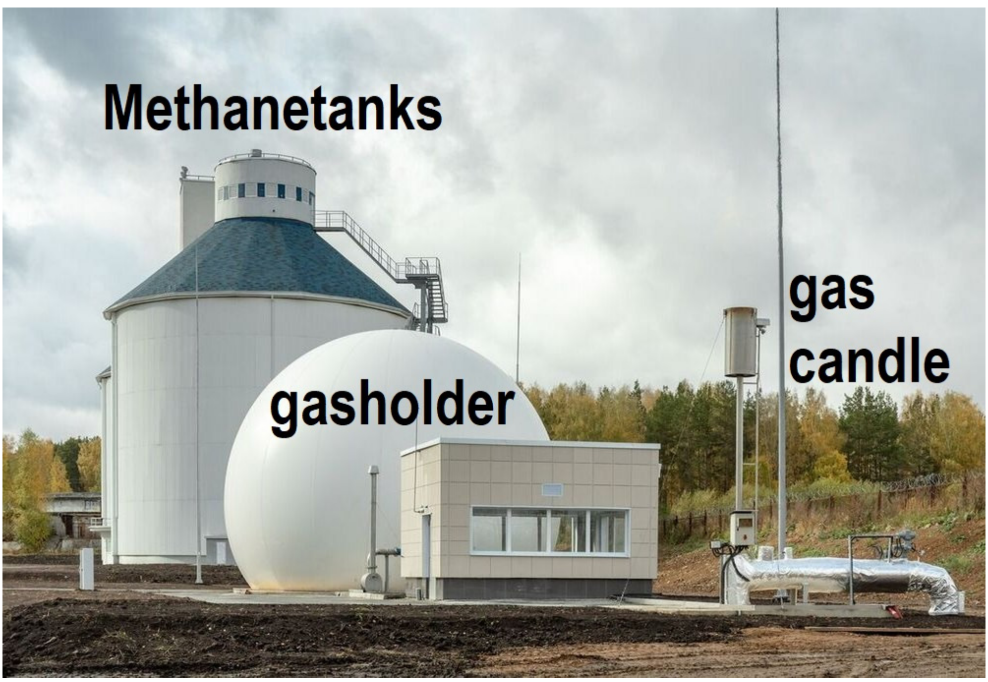

Figure 4: Biogas project implementation at Northern WWTP.

mixture of primary sludge and waste activated sludge is loaded into methane tanks with the average hydraulic retention time of 27 days. Total biogas production for Northern WWTP in Ekaterinburg is 3.5961 t/d (is equal to 2,969.45 Nm^3/d) with consideration of biogas losses from the anaerobic digestion process of 0.0108 t/d [1].

Ekaterinburg municipal enterprise of water supply and sanitation – the operator of the Northern WWTP – is an organization carrying out regulated business activities. These types of companies provide water supply and sanitation services at tariffs set by the local authorities.

2.3 Financial tools for the project implementation

The present quality of WWTP in most of Russia's cities and towns needs improvement. According to Russia's Ministry of Natural Resources, more than 70% of the approximately 9,000 WWTPs in operation today (within centralized sewerage systems) were built 30 to 50 years ago and 80% of them should be upgraded. Furthermore, some of it cannot be upgraded, but rather must be completely rebuilt. According to the Ministry of Natural Resources, the national modernization of WWTPs will require about $20 billion, while the Ministry of Construction consider the required annual investment rate for each of the next five years for "bringing the water supply and sanitation systems into conformity with standards" at $1.5 billion [28]. In this situation, the implementation of biogas projects at WWTP is the second step in the development of the utilities. However, for consequent transition towards circular economy, the most effective financial instrument is required to be determined.

As was mentioned above, all water supply and sanitation sector is regulated, so the issue to find suitable financing is of a great importance. Four typical financial tools for biogas project implementation were determined for regulated companies, operating the WWTPs in Russian Federation. These included the following:

- tariff sources established for wastewater service users,
- state or municipal budget,
- private investment,
- bank credits.

For each tool the following steps should be fulfilled:

- to describe an organizational chart with the definition of stakeholders and their relationship in the project;
- to analyze the interest of each stakeholder in terms of the benefits from the implementation of biogas projects;
- to identify the features of financing and assess the financial efficiency of the projects;
- to consider the differences in the application of described tools in developed countries and Russian Federation.

2.4 Assessment of the financial efficiency of the biogas project

Biogas project implementation grants the initiator a multiple effect: the detailed benefits were presented in Fig. 1. However, when considering financial instruments for project implementation, the economics of the project is a crucial issue. Speaking about the use of various financial tools, Return on Investment (ROI) and Payback period (PP) indicators were applied to assess the efficiency of the projects [29].

ROI is calculated using the following equation:

$$ROI(\%) = \frac{Annual\ net\ profit}{Total\ capital\ investment} \times 100\%. \quad (1)$$

PP is calculated using the following equation:

$$PP(years) = \frac{1}{ROI}. \quad (2)$$

Annual net profit correlate with the economic benefits, mentioned above, using the following equation:

$$\text{Annual net profit} = \text{Savings} + \text{Income} - OPEX_{BGP}, \quad (3)$$

where:

- savings ($) include savings on self-energy consumption of WWTP, savings on environmental payments;
- income ($) includes the income from resource extraction, income from the use of digested (post-treated) sewage sludge as fertilizer and income from energy supply to the grid;
- $OPEX_{BGP}$ ($) include operational expenditures for biogas project.

The financial equivalent of environmental and prestige factors is not taken into account under the current methodology.

Total capital investments ($) include the required amount of investment for biogas project implementation, including design and construction works for biogas yield, CHP-unit installation, all pre- and post-treatment techniques.

3 RESULTS AND DISCUSSIONS

The authors determined the investment costs of building infrastructure for biogas yield and CHP-unit for various financial instruments for the implementation of biogas projects under consideration.

In 2018, a biogas project was put into operation at the Northern WWTP as a part of the sewage sludge treatment and utilization workshop [30]. The project was implemented according to the investment program adopted by local authorities. According to the investment program reports [31], the actual capital cost for biogas project amounted to $4.29 million (hereinafter, all the cost values are presented in million $ at the exchange rate for 2018).

When the biogas facility was put into operation, biogas was utilized in a heating boiler for heat energy generation. However, this disposal method has limited use only during the heating season; the rest of the time the biogas was burned in a gas-candle. The CHP-unit as an alternative method of biogas utilization was designed to improve the efficiency of biogas use. Currently, due to lack of funding, the project has not yet been implemented, but the authors will consider project data. The project included the following set of works: supply, installation and connection of a CHP-unit based on the Jenbacher JGS 312 GS-B.L generating complex with maximum electric performance of 635 kW. The project cost was $0.69 million.

Thus, the total cost of implementing a biogas project for WWTP with a maximum inflow performance of 100,000 m^3/day was $4.97 million.

The annual net profit within the considered case study was calculated using the following input data.

1) Self-energy consumption savings: the total annual energy generation is 4,642,800 kWh/y, which covers more than 70% of self-energy consumption of Northern WWTP.

Electricity tariffs for Russia and some EU countries, and the total amount of savings from energy generation is presented in Table 2.

The electricity tariffs in Table 2 are set for purchasing the electricity from the grid in the retail market. Nowadays in Russia, a number of regulatory documents for establishing the special "green" tariffs for electricity produced at qualified generating facilities operating as renewable energy sources, has been approved. However, by the beginning of 2021, in Russia there was the only one qualified generation unit, that use biomass [[34]]. The qualification of generating unit for renewable energy facilities according to the official requirements is too complex and possible only if self-generation exceeds the self-consumption.

Table 2: Electricity tariffs and savings in Russia and some EU countries in 2021. *(Source: Prepared by the authors, using data from [32], [33].)*

	Russia	**France**	**Italy**	**Spain**	**Germany**
Tariff ($ per kWh)	0.0676	0.2107	0.2462	0.2532	0.3480
Savings ($) m. per year	0.314	0.978	1.143	1.176	1.616
Share compared with RU	100.00%	311.81%	364.40%	374.72%	515.07%

2) Savings on environmental payments. In Russia, companies responsible for water supply and sewerage pay a fee for negative environmental impact for sewage sludge disposal: the rates depend on the hazard class of the waste [35]. In common, sewage sludge belongs to waste hazard class IV, less often – to V waste hazard class. The process of AD does not directly affect the transition from hazard class IV to V – application of post-treatment techniques is required, e.g. composting of digested sludge. However, in this case, this technology is not used. It should be mentioned, that the effect of preventing GHG from being released into the atmosphere by application of AD, does not influence a particular WWTP in terms of environmental payments.
3) Additional income. In the current case study, techniques for valuable substances extraction are not applied. These techniques, in general, have limited use in Russian Federation due to priorities: high moral and physical deterioration of the main WWT infrastructure and lack of financial resources make the use of waste recovery inappropriate.

The use of sewage sludge in Russia without any post-treatment technique may be relevant for non-agricultural applications such as quarry and landfill remediation. At present, the market for purchasing the sewage sludge for agriculture has not been established yet, so no benefits are considered.

Actual operational expenditures for biogas infrastructure at Northern WWTP are $0.17 m, for CHP-unit are $0.07 m. These costs include the personnel wages, the cost of maintenance, current repairs and spares. The total annual cost is $0.24 m. In Table 3 OPEX was presented with the approximation of the former one in some developed EU countries. The estimated share of personnel costs with accordance of average monthly wages in Russia and EC [36]–[38] was used for the approximation procedure.

The annual net profit, ROI and PP for Russia and some developed EU countries were calculated, using eqns (3), (1) and (2) respectively. The outputs are presented in Table 3.

The obtained results correlate with similar indicators from other investigations [39], [40].

The use of the various financing instruments described in Section 2.3 in relation with the investment performance indicators is presented onwards.

Table 3: $OPEX_{BGP}$, annual net profit, ROI and PP for Russia and some EU countries.

	Russia	**France**	**Italy**	**Spain**	**Germany**
$OPEX_{BGP}$ (million $/year)	0.24	0.69	0.62	0.59	0.91
Annual net profit (million $)	0.07	0.29	0.52	0.59	0.71
ROI (%)	1.43	5.80	10.53	11.78	14.20
PP (years)	70.13	17.24	9.50	8.49	7.04

3.1 Tariff sources established for wastewater service users

Regulatory authorities establish tariffs for wastewater services, which include transportation of wastewater via sewerage and treatment at WWTP.

The activities of Russian companies responsible for water supply and sanitation are divided into operating and investment; so, tariffs may include a production and investment component, respectively. The first step for biogas project implementation is the adjustment of water supply and sanitation scheme – a strategic planning document for municipalities. The investment costs are included in Required Gross Revenue (RGR) and the investment program passes through complex approval process. After the program is approved, tariffs are calculated and established. The annual tariff growth in Russia is limited by the level of 4%–6%.

For the case study under consideration, a forecast for tariff growth was made due to the implementation of the biogas project: the results are presented in Table 4.

Table 4: Wastewater tariff increase for biogas project implementation.

Indicator	**1 year**	**3 year**	**5 year**
RGR ($ million)	4.97	1.66	0.99
Total inflow at Northern WWTP (million. cm^3)	20.72	20.72	20.72
Current (C) tariff ($)	0.38	0.38	0.38
Additional (A) tariff ($)	0.24	0.08	0.05
C + A tariff ($)	0.62	0.46	0.42
Increase rate (%)	164	121	113

The calculation was made according to three options: investment costs are included in the RGR for one, three and five years.

The investment costs for biogas project implementation accounted in tariffs lead towards the annual tariff growth of 113% with the maximum RGR period of five years – it exceeds the established boundaries for tariff growth. Shorter RGR periods produce even worse results. At the same time, the implementation of other high priority investment projects is not considered. An increase in tariffs above the established values is unlikely, but possible, which will certainly cause serious dissatisfaction among consumers of services.

This financial instrument is suitable for large organizations that have significant RGR value: adding the biogas project to the investment project will have minor impact on tariff growth rate.

3.2 State or municipal budget

The EU has encouraged the development of biogas plants for energy production by various support schemes to promote transition towards circular economy. The vast majority of developed countries have legislations and energy policies related to reducing GHG and mitigation of climate change [41].

To support the development of renewables, the European Commission has established a special financing mechanism, which has been in force since September 2020. This mechanism links countries that voluntarily pay (contributing countries) with countries that agree to have new projects built on their soil (hosting countries). EU supports the financial contributors with grants, which cover either the installation of a renewable production facility (investment support) or the actual production of renewable energy (operational support) [42].

In general, in developing countries, renewable energy targets are abandoned or progress in achieving them is slow [41]. In Russia, local authorities are implementing municipal and state programs aimed at developing communal services and increasing its energy efficiency. Due to budged limitations, only few projects, predominantly critical, receive governmental support. Basically, these are projects aimed at ensuring the standard quality of wastewater treatment or preventing serious accidents at WWTPs due to high wear and tear.

Financing of biogas projects from the municipal or state budget is possible in the form of co-financing together with other sources (e.g. private capital), or interest rate compensation when using bank loans. In addition, the considered financial instrument can be used for the implementation of inter-municipal biogas projects – to solve the problem of utilization of biodegradable waste not only from WWTP, but also from other industrial enterprises, accepting animal and crop waste, municipal solid waste.

3.3 Private investment

In Russia, most WWTPs are municipal or state-owned enterprises, but recently, concession agreement procedures were approved in legislation. Government motivates investors to assist with water supply and sanitation infrastructure through rewarding them with reasonable returns [43]. Local authorities approve the parameters of the concession agreement and a list of measures to modernize the facilities. High priority has the improvement of the quality of wastewater treatment, while the significant payback period of biogas projects does not create prerequisites for the implementation of them as a private initiative to improve the energy efficiency of WWTPs.

At the same time, a number of large concessionaires have approved and are implementing a corporate social responsibility (CSR) strategy: the implementation of biogas projects affects the perception of such organizations as advanced and environmentally-friendly, both by consumers of services and by municipal and state authorities, regulatory and inspection departments.

3.4 Bank credits

Bank credit is the provision of funds by a financial institution that the borrower undertakes to repay on time with interest. Debt from private or government-owned banks is a typical and traditional financing option for biogas investment projects. The main types of these instruments for biogas projects are:

- traditional financing by loans;
- project financing (limited recourse or non-recourse), and
- green bonds [44].

The water supply and sanitation companies have to repay the loan from its activities (in Russia – from investment activities). Funding source is tariff for wastewater services. This financial instrument can be an addition for tariff financing tool reducing the annual tariff growth rate due to decreasing the value of GRG for future periods. However, long term payments (the return of loans) for biogas projects reduce the scope for other investment projects, that are not related to biogas projects.

Recently, in Russian Federation, specific banking products have appeared, aimed at the support of the development of environmental and renewable energies, including biogas projects – green credits. Large banks, particularly state-owned banks, are more likely to lend green credits. Moreover, there is a reverse relationship between green lending and the government's anti-pollution investment – as the government spends more on improving the environment, there is less need for banks to lend green credits [45].

4 CONCLUSION

Potential financial instruments for the implementation of biogas projects, including tariff sources, budged funding, private investment and bank credits were considered within the manuscript. These projects allow the consistent transition towards circular economy principles.

However, poor quality of wastewater treatment and the significant moral and physical deterioration of the utilities remain an urgent problem for WWTP managers and local authorities, responsible for communal services, in Russian Federation. These issues prevent the transition towards the next stage of WWTP modernization aimed at ensuring the environmental safety of territories and increasing the energy efficiency of facilities due to implementation of biogas projects.

Implementation of biogas projects in Russian Federation is limited by low return on investment and extremely long payback period compared to those that can be achieved in developed countries. This is the result of the low cost of energies, as well as insufficient government support for green projects aimed at developing renewable energy.

Thus, the use of the considered financial instruments in Russian Federation is insufficient and ineffective, but has made moderate progress: the state, private business and the public entities show growing interest to biogas projects every year.

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