Analysis of the resource potential of biogas production in the Russian Federation

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Abstract. The accumulation of organic waste is a significant environmental problem in Russia. Organic waste is a valuable source of raw materials, which can be used to produce biogas and biofertilizers. The production of biogas is possible from sewage sludge, formed at the municipal wastewater treatment facilities, livestock waste in agricultural enterprises and organic food fraction of municipal solid waste. According to our estimates, the total amount of organic waste in Russia suitable for the formation of biogas and biofertilizers is about 167.8 million tons per year. The main part of this waste is made up of livestock waste (90%), 6% is a fermentable fraction of the municipal solid waste and 4% originate from the sewage sludge. The Central and Volga federal districts possess the greatest potential for organic waste (54 and 43 million tons respectively). At present, the actual use of organic wastes potentially capable of serving as raw materials for the production of biogas is 2-3 orders of magnitude lower than the available potential of the organic waste.

1. Introduction
The accumulation of organic waste represents a significant environmental problem and at the same time the organic waste is an important source of raw materials for the biogas production. Among the main measures to improve energy efficiency, the "Energy Strategy of Russia" envisages a reduction in consumption of non-renewable fuel and energy resources and the maximum possible use of renewable energy sources [1].

However, not all available types of organic waste can be economically and technologically efficiently processed into biogas. For example, the municipal solid waste (MSW) is characterized by a high content of organic components (up to 50-60% of the total weight) [2]. The food waste most easily decomposed by microorganisms accounts for 24-30% of the MSW, whereas paper and cardboard components accounts for 38-42% of the volume of MSW are decomposed by microorganisms for a long time, which reduces the efficiency of the process. In addition to food waste, sewage sludge and livestock waste can be anaerobically processed with biogas production [3].

To fully utilize Russia's organic waste resources, a strategy based on the most accurate assessment of the technical potential of organic waste and its spatial distribution is necessary. A correct assessment of the technical potential is difficult due to the imperfection of the systems of accounting of organic waste and the discrepancy between the statistical data collected by various departments. Assessment of the potential of organic waste suitable for biogas production in Russia was carried out earlier by a team of authors led by Bezruki with the use of statistical data obtained in the early 2000s [4]. Also, the assessment of the energy potential of Russia's biomass resources was carried out by Namsaraev and...
Nevertheless, the authors did not carry out a separate assessment of the potential of organic waste suitable for the production of biogas and biofertilizers, since the volumes of the MSW fraction suitable for biogas production were not estimated.

Thus, the goal of this article is to analyze the technical resource potential and geographical distribution of organic waste that can be used for biogas production in the Russian Federation.

2. Materials and methods

To estimate the amount of livestock waste, the data obtained from the reports of the Ministry of Agriculture of the Russian Federation on the livestock population in Russia [6] were used. Only the data on agricultural enterprises, where collection and processing of waste can be organized, were taken into account. Data were taken into account for the number of cattle, pigs, and birds, for which stall maintenance is mainly used. Species of animals with predominantly free grazing (camels, reindeer, etc.) were not taken into account due to the impossibility of economically efficient disposal of their waste.

When assessing the amount of waste generated, the methodological recommendations of the Ministry of Agriculture of the Russian Federation [7] were used. For cattle, the formation of waste in the amount of 30 kg per day with a humidity of 85%, for pigs the formation of waste in the amount of 4 kg per day with a humidity of 85%, for birds the formation of waste in the amount of 0.2 kg per day with a humidity of 75%.

The amount of livestock waste by wet weight (LW) per year in tons for each animal species was calculated using a formula:

\[ LW = 365 \times WH \times NA \times 1000, \]

where 365 is the number of days in a year,

WH - the amount of waste per day from one animal in kg,

NA - number of animals in agricultural enterprises,

1000 - factor for recalculation of kg in tons.

Earlier the amount of MSW was estimated in the city of Moscow, which is 400 kg per year per capita [8]. The food waste available for fermentation and methane production is 24-30% of the MSW volume [8]. In our paper, a coefficient of 25% of the MSW volume is taken, so the amount of waste suitable for biogas production is 0.1 tons of food waste per capita per year. Data on the number of people were obtained from the Goskomstat database of the Russian Federation. We took into account only the urban population, due to the difficulty in estimating the amount of organic waste available for processing from the rural population.

The estimation of the amount of sewage sludge was made using the data of the Russian Association of Water Supply and Sanitation published on the website of the Federation Council of the Federal Assembly of the Russian Federation [9]. According to these data, an average of about 10 833 million m³ of wastewater was treated annually by the municipal wastewater treatment plants. In 2015, about 5.6 million tons of sewage sludge was formed with a 75% moisture. Taking into account the fact that the number of people with an access to the centralized water distribution network in 2015 was 91959802 people, the volume of the formed sewage sludge with a humidity of 75% was about 0.061 tons per capita per year.

3. Results

According to the Russian Ministry of Agriculture in 2012, the total number of livestock and poultry in Russia amounted to 19.9 million head of cattle, 18.8 million pigs, 24.1 million head of sheep and goats, and 495 million birds [6]. According to the results of a study carried out in Russia under the TACIS program, the generation of heat and energy from waste is economically feasible only on commercial farms with a number of animal of over 500 head for cattle, 1000 to 2000 heads for pigs, and 50 and 100 thousand for hens and broilers respectively [10]. According to the data for 2016, the number of animal at the agricultural enterprises was 8.3 million head of cattle, 18.3 million pigs, and 451.5 million head of birds [6]. The quantity of wet manure at the enterprises (technical potential), calculated according to the methodological recommendations of the Ministry of Agriculture of the Russian Federation, in wet
form was 151.3 million tons in 2016. The largest amount of manure was produced in the cattle farms - 91 million tons. The amount of manure in the poultry and pig farms was 32 and 26 million tons, respectively. The Central and Volga federal districts (FD) have the largest potential of the livestock waste (49 and 40 million tons respectively) (Table 1).

Table 1. Livestock number in commercial agricultural organizations

|                          | Number of livestock in agricultural organizations, million heads, the value of the indicator for 2016 | Wet weight of waste as of 2016, million tons |
|--------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------|
|                          | Cattle  | Birds  | Pigs  | Cattle  | Birds  | Pigs  | Total  |
| Russian Federation       | 8.3     | 451.5  | 18.3  | 91.4    | 32.9   | 26.8  | 151.3  |
| Central FD               | 2.1     | 151.2  | 9.8   | 24.0    | 11.0   | 14.4  | 49.5   |
| North-West FD            | 0.5     | 44.5   | 1.4   | 6.0     | 3.2    | 2.1   | 11.4   |
| Southern FD              | 0.5     | 35.8   | 0.8   | 6.5     | 2.6    | 1.2   | 10.4   |
| North-Caucasian FD       | 0.3     | 21.4   | 0.3   | 3.2     | 1.5    | 0.4   | 5.3    |
| Privolzhsky FD           | 2.6     | 97.0   | 2.7   | 29.4    | 7.0    | 3.9   | 40.5   |
| Ural FD                  | 0.4     | 48.2   | 1.2   | 5.1     | 3.5    | 1.7   | 10.4   |
| Siberian FD              | 1.4     | 44.9   | 1.6   | 15.8    | 3.2    | 2.4   | 21.5   |
| Far Eastern FD           | 0.1     | 8.2    | 0.2   | 1.1     | 0.6    | 0.3   | 2.1    |

The estimated amount of MSW fraction suitable for biogas production is 10.8 million tons per year. The Central and Volga federal districts (3.2 and 2.1 million tons respectively) have the greatest potential of the MSW (Table 2).

According to the Russian Association of Water Supply and Sanitation data, about 5.6 million tons of sewage sludge with 75% moisture was formed in 2015. According to our calculations, the Central and Volga federal districts (1.6 and 1 million tons respectively) have the greatest potential for sewage sludge (Table 2).

Table 2. The amount of organic waste suitable for biogas formation in the federal districts of the Russian Federation

|                          | Estimated amount of MSW food fraction, million tons per year | Estimated amount of sewage sludge, million tons per year | Estimated amount of livestock waste, wet weight, million tons per year | Total amount of organic waste suitable for biogas formation, million tons per year |
|--------------------------|-------------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Russian Federation       | 10.8                                                        | 5.6                                                    | 151.3                                                                | 167.7                                                                            |
| Central FD               | 3.2                                                         | 1.6                                                    | 49.5                                                                 | 54.3                                                                             |
| North-West FD            | 1.1                                                         | 0.6                                                    | 11.4                                                                 | 13.1                                                                             |
| Southern FD              | 1.0                                                         | 0.5                                                    | 10.4                                                                 | 11.9                                                                             |
| North-Caucasian FD       | 0.4                                                         | 0.2                                                    | 5.3                                                                  | 6.0                                                                              |
| Privolzhsky FD           | 2.1                                                         | 1.0                                                    | 40.5                                                                 | 43.7                                                                             |
| Ural FD                  | 0.9                                                         | 0.5                                                    | 10.4                                                                 | 11.9                                                                             |
| Siberian FD              | 1.4                                                         | 0.7                                                    | 21.5                                                                 | 23.6                                                                             |
| Far Eastern FD           | 0.4                                                         | 0.2                                                    | 2.1                                                                  | 2.8                                                                              |
Estimates of the actual use of the bioenergy potential of livestock in Russia have not been conducted previously. In the register of qualified renewable energy generating facilities, there is only one biogas power station "Luchki" in the Belgorod region with a capacity of 2.4 MW [11]. At present, it is the largest biogas power plant operating in Russia that use livestock wastes [12]. The annual consumption of livestock waste at the plant is 98 thousand m3. According to Namsaraev and co-authors, the total capacity of Russian power plants using biogas from livestock wastes is at least 3.1 MW [5]. The annual consumption of livestock wastes for production is approximately 240 thousand m3 per year, which is 0.17% of the total amount of manure produced in Russian agricultural enterprises.

Such an insignificant volume of livestock waste utilization represent a serious problem for agriculture and ecology [13]. The low capacity of manure storage facilities, as well as the absence of agricultural land in a number of farms, leads to the fact that in many farms the volume of manure exceeds the volumes of manure storage facilities by 1.5-2 or more times. As a result, farms are forced to locate manure on unprepared sites, where it pollutes water reservoirs and lands around manure storages, and also leads to conflicts with local population and controlling organisations. In the future, the number of livestock in agricultural organizations will constantly increase and, consequently, the amount of manure obtained will increase [13].

At present, 97% of the total volume of MSW produced in Russia is stored in landfills, 2% is burned and 1% is composted [14]. The area occupied by MSW landfills in Russia exceeds 40,000 ha and annually increases by 2.5-4% [15]. In Russia, separate collection of MSW is practiced in limited quantities, and only a small part of the waste is subjected to preliminary mechanical treatment (pressing). Despite the existence in Russia of a number of programs for the development and reconstruction of MSW landfills, most of them don't correspond to the modern standards.

Currently, in Russia, the two largest facilities for obtaining biogas from sewage sludge works at the sewage treatment plants in Moscow. A mini power plant was built at the Kuryanovskiy sewage treatment plant, which generates 10 MW of electric power and 6.9 Gcal/h of heat. At the Lubertsy sewage treatment plant, all biogas is used to produce heat of 32.6 Gcal/h. Kuryanovskiy and Lyubertsy sewage treatment plants generate 128 thousand and 145 thousand cubic meters of biogas a day. The resulting sewage sludge is also disposed of in the MSW landfills. In this case, sewage sludge is pre-compacted on special equipment (centrifuges, press filters, etc.) or by aging for several years on sludge sites. An alternative use of sewage sludge is fertilizer, while meeting the requirements for the content of heavy metals, pathogenic microorganisms and other pollutants.

Thus, at present, the actual use of organic wastes potentially suitable for biogas production is 2-3 orders of magnitude lower than the available potential for organic waste.

4. Conclusion
The total amount of organic waste suitable for biogas formation is 167.8 million tons per year. Of these, the main part is made up of animal waste (90%), 6% is waste of fermentable organic MSW fraction and 4% of sewage sludge. The Central and Volga federal districts possess the greatest potential for organic waste (54 and 43 million tons respectively). At present, the actual use of organic wastes suitable for the production of biogas is 2-3 orders of magnitude lower than the available potential for organic waste.

Acknowledgements
This work was supported by Ministry of Education and Science of the Russian Federation (project identifier RFMEFI60417X0190).

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