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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:

International Journal of Energy Economics and Policy (IJEEP)

Reference: Omarov, Zhomart/Kalykov, Abay et. al. (2021). Opportunities and potential of bioenergy development in agroindustrial complexes of Kazakhstan. In: International Journal of Energy Economics and Policy 11 (6), S. 91 - 97.

<https://www.econjournals.com/index.php/ijEEP/article/download/11530/6104>.

doi:10.32479/ijEEP.11530.

This Version is available at:

<http://hdl.handle.net/11159/7867>

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Opportunities and Potential of Bioenergy Development in Agro-industrial Complexes of Kazakhstan

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Received: 21 May 2021

Accepted: 29 August 2021

DOI: <https://doi.org/10.32479/ijeeep.11530>

ABSTARCT

The article examines the possibility of developing bioenergy in the agro-industrial complexes of Kazakhstan which can reduce greenhouse gas emissions into the atmosphere and solve problems associated with the disposal of agricultural waste. Special attention is paid to bioenergy generation technologies in agro-industrial complexes which require high capital expenditures to be equipped with modern automation and control facilities. The authors analyse the potential of biogas production from livestock and poultry waste in the agro-industrial complexes of Kazakhstan. During the analysis, it was revealed that the largest volumes of organic waste are produced by cattle breeding, and the smallest – by poultry farming. The article presents an assessment method based on the construction of a two-factor correlation-regression model, in which the effective (endogenous) factor feature is the total production of biogas and the total biomass is selected as an independent (exogenous) factor feature. The results of the calculations showed that the models reflecting the dependence of the total biogas production on the total biomass for cattle, sheep and goats, as well as poultry, correspond to the real flow of processes in the economy and logic.

Keywords: Alternative Energy Source, Bioenergy, Green Economics

JEL Classifications: Q42, Q50

1. INTRODUCTION

Kazakhstan is one of the largest agro-based economies in Central Asia which boasts expansive crop cultivation that generates huge amounts of agricultural residues. There have been intentions to convert these residues into bioenergy for cooking, heating, and electricity production. Currently, the conversation of agricultural residues to heat is limited to only a few biomass-based boiler plants, although integration of renewable energy into energy balance is highly considered as a number priority in the countries realization of green economy strategy.

The Concept for the transition of the Republic of Kazakhstan to a “green economy” (2013) provides that by 2030, the structure of electricity production by 10% should consist of renewable

energy sources (RES). For this purpose, the Decree of the Government of the Republic of Kazakhstan (2014) “On approval of fixed tariffs” approved fixed tariffs for 15 years for each type of renewable energy. When approving fixed tariffs for bioenergy, the international obligations of the Republic of Kazakhstan to reduce greenhouse gas emissions were taken into account.

The conversion of unused agricultural residues to energy is one way to increase the country’s share of renewable energy. This makes renewable energy from agricultural residues is scalable because of the enormous potential it currently holds.

This paper aims to point out the opportunities and potential of bioenergy development in agro-industrial complexes with the focus being on Kazakhstan.

To achieve the goal, the following tasks must be completed:

- Review the literature on the production of bioenergy from agricultural waste
- Consider bioenergy generation technologies
- Analyze the potential of bioenergy development in Kazakhstan
- Evaluate the conversion of agricultural waste to bioenergy.

2. LITERATURE REVIEW

Currently, many scientists are studying the problems of recycling agricultural waste with the possibility of using it in the country's energy sector.

Their research examines the prospects for the use of renewable energy sources in agriculture (Bolyssov, 2019) and the possibility of using organic waste as a primary resource for the production of biogas, electricity and heat (Tasmaganbetov, 2020).

According to Babaeva et al. (2017), green energy or renewable energy is processed from various physical processes. The main purpose of this form of energy is to limit the number of greenhouse emissions, reduce the over-dependence on fossil fuel that is associated with volatility in the fuel markets. Moreover, the utilization of renewable energy also contributes to the countries environmental and energy goals. Currently, there is an enormous potential for Kazakhstan to convert agricultural residues to bioenergy. These residues make up crop cultivation, animal husbandry, which makes this undertaking viable because of the availability of raw materials. According to the recent visibility study, that summarized Kazakhstan's potential of availability for crop residues for energy conversion in Kazakhstan.

The production of energy from biomass volume involves a range of technologies that includes solid combustion, fermentation, gasification among others. These technologies produce gas and liquid fuels from a diverse set of biological sources, including crop residues, wastes, and traditional crops. There is also dung and organic component of urban waste. All this produce bioenergy that is used for various purposes including heating, cooking fuel, electricity, and transportation fuels (De Corato et al., 2018).

This diversity makes bioenergy development suitable for all stakeholders that range from policymakers to the final consumer. It has environmental, social, and economic benefits, thus, the issue at hand is developing an international framework with backup strong domestic policy instruments. Moreover, bioenergy derived from sustainable agriculture practices provides an opportunity for the country to utilize its resources and attract the necessary stakeholders to accelerate its sustainable development process. Some of the benefits that come with the development of bioenergy include environmental benefits from the reduction of greenhouse gases and the recuperation of soil productivity and degraded lands. The economic benefits could result from increased activity that will be a result of improved access to quality energy services (Beltrán-Ramírez et al., 2019).

Other benefits come with bioenergy development, for instance, bioenergy development is associated with poverty alleviation

and development. The first set of critical energy needs includes those that satisfy human needs which includes, fuel for cooking and heating, electricity for health and education services, and energy for pumping water. Another set of these critical energy needs includes those that provide energy for income generation which helps break the cycle of poverty. For instance, Brazil is one such country that has benefits from biofuels, the country has had a sustainable ethanol production. Sugar cane is the main source of biofuel which is transferable to other countries (Fytli and Zabaniotou, 2018).

As it can be seen, the development of bioenergy with well-thought-out management can reduce greenhouse gas emissions into the atmosphere, solve problems associated with the disposal of agricultural waste and increase the energy security of agriculture.

3. TECHNOLOGIES FOR THE PRODUCTION OF BIOENERGY

There are several technologies around the world being used to convert agricultural residues or waste to energy. However, biomass for energy continues to be the main source of renewable energy in several countries across the world. The current trends indicate that the heating and cooling sectors continue to be the large end-user consuming about three-quarters of all the bioenergy (Fernandez-Mena et al., 2016). In Kazakhstan the technology of converting agricultural residues is still in early stages, therefore the paper proposes some solutions as indicated below:

3.1. Crop Residues Combustion on Biomass Heat only Boilers

This technology has a CAPEX capacity of 700,000 EUR/MW. This technology involves the combustion of the agricultural residues in standalone biomass boilers and the production of heat. Feedstock are fed to grate boilers and after the combustion, heat is used for the local purpose such as space heating, and domestic hot water. The main raw material for use in this technology are crop residues and dry organic residues (Mellor et al., 2021).

3.2. Crops Residues Co-firing in the Existing Large only Boiler Plants

This technology has a CAPEX capacity of 150000 EUR/MW and involves the agricultural residues in an existing boiler which is fed by a limited amount of biomass into the furnace and production of heat. Moreover, the feedstock are crushed into dust in large crushers and fed to existing boilers and after the combustion, heat is used for the local purpose such as space heating, domestic hot water, and process heat of higher temperatures. The main raw materials used for this technology include dry organic residues, and crop residues (Ghimire et al., 2017).

3.3. Biogas Plants

This technology produces methane gas, through the fermentation of organic matter process. The feedstock is transported to plants and after anaerobic process biogas is then generated. Some of the output products that are involved in this process include biogas, and digestate which could be used as fertilizer.

The country stands to benefit from the deployment of energy conversion system, for instance, it could benefit from less GHG emissions, Carbon dioxide, and nitrous dioxide gases into the atmosphere. Although agro-residue handling requirements and volume vary across the country, this volume could be captured and combined across different farms in a single specific facility, where it can be processed and converted to energy. Besides, the unused agricultural residues conversion also ensures the production of useful heat that can then be used for both local and industrial sectors or electricity that can be absorbed into the national and local grid. There is also the aspect of byproduct that comes with the process, in this case, is fertilizer which could be used in other farming activity across the country and also increase soil fertility. The process also enables recirculation of the organic and green waste from farms. It also enables better waste management process at local and industrial levels (Suhartini et al., 2020).

There is also the aspect of the Sustainable Development Goals, clean energy technology will help the country realize these goals faster. For instance, access to clean energy such as biomass energy can help to minimize gender inequalities and the variations in energy access across different gender dimensions, cultural and social contexts. Besides, the introduction of cleaner energy, and renewable fuel sources, can bring training, entrepreneurial, and employment opportunities for different communities across the country. Modern and improved energy services have the potential of improving the socio-economic status of women by reducing the amount of time required for household chores (Markou et al., 2018).

Today majority of the manure digested to biogas is in form of slurry, although it is also possible to produce biogas for solid manure. However, the process is slow and has far less desirable economic outcomes, even in cases where subsidies are available. The Slurry is fed to a digester tank where the carbon content in the slurry is broken down into methane which is later used as fuel. In digester are normally air-tight, in there, bacteria decomposes organic materials in the absence of air which then releases methane and carbon dioxide.

Acid-forming bacteria break down the volatile acids to methane and carbon dioxide. These bacteria are sensitive to changes in their environment. For rapid digestion and efficient biogas production to occur the environment has to maintain a given temperature. That is, the optimum gas production occurs in specific temperature ranges. For instance, Mesophilic bacteria thrive in temperature around 35°C or 95°F and thermophilic in the 120°F–140°F or 49°C–60°C (Mouratiadou et al., 2020).

The main components of the digester system include a slurry handling system, slurry preparation area, manure pump, and effluent tank. Other components include housing for the heating, agitation, and hydraulic equipment. The digester can either load the slurry continuously or by the batch. Once the batch is filled to the required capacity, it will be sealed until it has produced all the biogas, then it will be emptied and filled again. It is also worth noting that biogas production is not consistent because bacterial digestion normally starts slowly, peaks, and then tapers off as

the volatile solids are consumed. However, this can be solved by connecting a series of batch-load digesters that have been loaded at different times, this way a dependable amount of gas available at all times (Searchinger et al., 2017).

The digester has rigid walls, agitation equipment, and a minimum area to manage heat loss. The technology will utilize Combined Heat and Power plant where give farms will be utilized manure residues and crop residues as an organic mix. The mix will be sent to the biogas plant for anaerobic digestion. The main output for this design will be digested and biogas. The digestate will be used as fertilizer on the other hand the biogas will be used to produce electricity and heating for the neighboring community (Smith et al., 2017).

The biogas produced by the digester will be approximately 70% methane and 30% carbon dioxide. This implies that the quality of the gas is 70% energy or 28 MJ/M³. However, the methane content of the biogas will fluctuate according to the digester conditions. The hydrogen sulfide that is contained in the gas will be filtered through passing the gas through iron fillings given the gas is warm when it leaves the digester.

The current situation in the country is that farmers benefit from the captured agricultural residues schemes in some ways, for instance, manure is used as fertilizer, which reduces expenditure on organic fertilizer. There is another part of residues that are used as animal feed bedding. Nonetheless, a large part of unused residues could potentially help farmers to benefit from the production of additional alternative energy volumes and revenue streams, and high-quality fertilizer (Hassan et al., 2019).

As it can be presented, biogas is produced in biogas plants wherever bio-waste is available and is consumed immediately. Animal waste is of interest from the point of view of its use for the production of biogas and energy only if the animals are concentrated in confined spaces. In this case, there is a possibility of economically justified collection of manure with minimal or no dirt impurities. The use of anaerobic digestion of manure for the production of biogas and organic fertilizers will be very effective for various types of farms and farms that are remote from centralized energy supply systems. Nevertheless, the introduction of biogas technologies in agro-industrial complexes requires high capital expenditures. The level of these investments depends on the capacity of the installation, the equipment with modern automation and control tools, and the manufacturer of specific devices.

4. ANALYSIS OF THE POTENTIAL FOR THE DEVELOPMENT OF BIOENERGY IN THE AGRO-INDUSTRIAL COMPLEXES OF KAZAKHSTAN

The agro-industrial complex of Kazakhstan today faces the problem of recycling a huge amount of waste – most often they are simply exported from the territories of farms and stored. This leads to problems of soil oxidation, alienation of agricultural

land, contamination of groundwater and emissions of methane, a greenhouse gas, into the atmosphere.

According to the Statistics Committee of the Ministry of National Economy of the Republic of Kazakhstan (2020), the country has an annual increase in the number of livestock and birds (Table 1).

Over the past 10 years, the Republic of Kazakhstan has seen an increase in the number of cattle (1.26 million heads), sheep and goats (1.17 million) and birds (12.24 million). Large livestock complexes and poultry farms in modern conditions remain the most harmful environmental pollutants. In the same places, the population is concerned about the unpleasant smell caused by the decomposition of biological waste from livestock activities or the introduction of manure into the fields.

One of the possible solutions to this problem is the implementation of projects for the production of biogas from livestock and poultry waste in agro-industrial complexes. Agricultural waste will be the main raw material for generating electricity and heat.

The potential of biogas production from livestock and poultry waste in the Republic of Kazakhstan is presented in Table 2.

According to the data obtained (Table 2), in the Republic of Kazakhstan, the annual output of livestock and poultry waste by dry weight – 23.3 million tons can give 8.9 billion tons. m³ of biogas.

Depending on the type of organic feedstock, the composition of biogas may vary, but, in general, it includes methane (CH₄), carbon dioxide (CO₂), a small amount of hydrogen sulphide (H₂S), ammonia (NH₃) and hydrogen (H₂).

Since biogas consists of 2/3 of methane—a combustible gas that forms the basis of natural gas, its energy value (specific heat of combustion) is 60-70% of the energy value of natural gas, or about 7000 kcal per m³. 1 m³ of biogas is also equivalent to 1.5-2.2 kW/h of electricity and 2.8-4.1 kW/h of heat.

Analysis of the potential for bioenergy production from agricultural waste showed that the largest volumes of organic waste

are generated by cattle breeding (26152.5 MW/h of electricity and 48818 MW/h of heat), and the smallest – poultry farming (968.88 MW/h of electricity and 1805.64 MW/h of heat). The use of biogas plants will generate 41.7 million MW/h of bioenergy per year.

Thus, the introduction of biogas plants will significantly improve the environmental situation near large agro-industrial complexes, as well as in the territories where animal waste is currently dumped, and reduce the cost of environmental payments.

4.1. Assessment Conversion of Agricultural Waste to Bioenergy

The authors propose a method of estimating, based on the construction of two-factor regression models in which effective (endogenous) factor common symptom is the production of biogas (y).

As an independent (exogenous) in the factor variable is selected the total biomass (x).

In General, the two-factor regression model is as follows (Gusarov, 2001):

$$\hat{y}_x = a_0 + a_1 \cdot x \quad (1)$$

To find the parameters a_0 and a_1 , the following system of linear equations is used (Shmoylova et al., 2006):

$$\begin{cases} a_0 \cdot n + a_1 \cdot \sum x = \sum y \\ a_0 \cdot \sum x + a_1 \cdot \sum x^2 = \sum y \cdot x \end{cases} \quad (2)$$

To determine the reserves available in an independent factor attribute, an elasticity coefficient is used, which shows the average change in the effective attribute \hat{y}_x when the factor attribute x changes by 1%.

In general, the coefficient of elasticity is defined as follows (Gusarov, 2001):

$$\varepsilon = a_1 \cdot \frac{\bar{x}}{\bar{y}} \quad (3)$$

Table 1: Number of livestock and birds in the Republic of Kazakhstan for 2010-2019 amount in millions

Source of biogas	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average amount
Cattle	6.18	5.70	5.69	5.85	6.03	6.18	6.41	6.76	7.15	7.44	6.34
Sheep and goats	17.99	18.09	17.63	17.56	17.91	18.02	18.18	18.33	18.69	19.16	18.16
Birds	32.78	32.87	33.47	34.17	35.02	35.63	36.91	39.91	44.34	45.04	37.01

Source: Compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

Table 2: Potential of biogas production using livestock and poultry waste in the Republic of Kazakhstan

Source of biogas	Average livestock, numbers in millions	Biomass, kg/day per unit	Total biomass, ton/day	Volume of biogas produced from 1 kg of biomass, m ³	Total biogas production thousand m ³ /day
Cattle	6.34	55	348700	0.05	17435
Sheep and goats	18.16	6	108960	0.06	6537.6
Birds	37.01	0.17	6291.7	0.07	440.4
Total	-	-	463951.7	-	24413
Annual volume of biomass and biogas	-	-	23342370.5	-	8910745

Source: Compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

where a_i – regression coefficient for the factor x ;
 \bar{x} – the average value of an independent factor attribute;
 \bar{y} – the average value of the studied indicator.
 Θ – the coefficient of elasticity, which shows how many percent the effective factor attribute will change with a 1% change in the independent factor attribute.

To determine the parameters of the model (1), the authors performed separate calculations for the total biomass and total biogas production for cattle, sheep and goats, as well as poultry (Tables 4-6).

Therefore, three models and three elasticity coefficients are defined, respectively.

After substituting the total values of Table 4, the system of linear equations (2) will look like this:

$$\begin{cases} 5 \cdot a_0 + 1844996 \cdot a_1 = 94558 \\ 1844996 \cdot a_0 + 686511170936 \cdot a_1 = 35247237626 \end{cases} \quad (4)$$

Having solved this system, we have:

$$\begin{cases} a_0 = -4059,79 \\ a_1 = 0,0622 \end{cases} \quad (5)$$

Thus, the desired model (1), reflecting the dependence of the total biogas production on the total biomass obtained from cattle, will look like this:

$$\hat{y}_x = 0,0622 x - 4059,79 \quad (6)$$

We will determine the reserves laid down in the independent (exogenous) factor. To do this, we calculate the elasticity coefficient using the formula (3).

$$\Theta = 0,0622 \cdot \frac{(1844996 / 5)}{(94558 / 5)} = 1,2147 \quad (7)$$

In general, we have the following:

- The sign of the coefficient a_1 in the model (6) corresponds to the real flow of processes in economics and logic
- If the total biomass obtained from cattle increases by 1%, the total production of biogas will increase by 1.2147%.

After substituting the values of Table 5, the system of linear equations (2) will look like this:

$$\begin{cases} 5 \cdot a_0 + 543704 \cdot a_1 = 30341 \\ 543704 \cdot a_0 + 59124070216 \cdot a_1 = 3299363747 \end{cases} \quad (8)$$

Table 3: Potential of bioenergy production using livestock and poultry waste in the Republic of Kazakhstan

Source of biogas Cattle	Total biogas production thousand m ³ /day	Energy generation rate, per 1 m ³		Bioenergy generation	
		Electricity, kW/h	Heat energy, kW / h	Electricity, MW / h	Heat energy, MW/h
Sheep and goats	17435	1.5	2.8	26152.5	48818
Birds	6537.6	2.0	3.6	13075.2	23535.36
Total	440.4	2.2	4.1	968.88	1805.64
Source of biogas	24413	-	-	40196.58	74159
Annual production of bioenergy, MW / h				41739786.7	

Source: compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

Table 4: Data for calculating parameters a_0 and a_1 in the model (1) for cattle

Year	Numbers in millions	Total biomass, tons/day, x	Total biogas production, thousand m ³ /day, y	x^2	$x \cdot y$
		total biomass/per day, x	y total output of biogas/m ³ /per day, y		
2015	6.18	327 850	16 010	107 485 622 500	5 248 878 500
2016	6.41	332 080	17 340	110 277 126 400	5 758 267 200
2017	6.76	374 820	18 510	140 490 032 400	6 937 918 200
2018	7.15	402 990	20 357	162 400 940 100	8 203 667 430
2019	7.44	407 256	22 341	165 857 449 536	9 098 506 296
Total		1 844 996	94 558	686 511 170 936	35 247 237 626

Source: compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

Table 5: Data for calculating parameters a_0 and a_1 in the model (1) for sheep and goats

Year	Numbers in millions	Total biomass, tons/day, x	Total biogas production, thousand m ³ /day, y	x^2	$x \cdot y$
		total biomass/per day, x	total output of biogas/m ³ /per day, y		
2015	18.02	108 001	6 002	11 664 216 001	648 222 002
2016	18.18	108 327	6 050	11 734 738 929	655 378 350
2017	18.33	108 965	6 089	11 873 371 225	663 487 885
2018	18.69	109 030	6 190	11 887 540 900	674 895 700
2019	19.16	109 381	6 010	11 964 203 161	657 379 810
Total		543 704	30 341	59 124 070 216	3 299 363 747

Source: Compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

Table 6: Data for calculating parameters a_0 and a_1 in the model (1) for birds

Year	Numbers in millions	Total biomass, tons/day, x total biomass/per day, x	Total biogas production, thousand m ³ /day, y total output of biogas/m ³ /per day, y	x^2	$x \cdot y$
2015	35.63	6 037	453	36 445 369	2 734 761
2016	36.91	6 099	426	37 197 801	2 598 174
2017	39.91	6 342	478	40 220 964	3 031 476
2018	44.34	7 008	482	49 112 064	3 377 856
2019	45.04	7 124	503	50 751 376	3 583 372
Total		32 610	2 342	213 727 574	15 325 639

Source: Compiled by the authors according to the statistics Committee of the Ministry of national economy of the Republic of Kazakhstan (2020)

Having solved this system, we have:

$$\begin{cases} a_0 = 974,06 \\ a_1 = 0,05 \end{cases} \quad (9)$$

Thus, the desired model (1), reflecting the dependence of the total biogas production on the total biomass obtained from sheep and goats, will look like this:

$$\hat{y}_x = 0,05 \cdot x + 974,06 \quad (10)$$

We will determine the reserves laid down in the independent (exogenous) factor. To do this, we calculate the elasticity coefficient using the formula (3).

$$\mathcal{O} = 0,05 \cdot \frac{(543\,704 / 5)}{(30\,341 / 5)} = 0,8395 \quad (11)$$

In general, we have the following:

- The sign of the coefficient a_1 in the model (10) corresponds to the real flow of processes in economics and logic
- If the total biomass obtained from sheep and goats increases by 1%, the total biogas production will increase by 0.8395%.

After substituting the values of Table 6, the system of linear equations (2) will look like this:

$$\begin{cases} 5 \cdot a_0 + 32\,610 \cdot a_1 = 2\,342 \\ 32\,610 \cdot a_0 + 213\,727\,574 \cdot a_1 = 15\,325\,639 \end{cases} \quad (12)$$

Having solved this system, we have:

$$\begin{cases} a_0 = 149,43 \\ a_1 = 0,049 \end{cases} \quad (13)$$

Thus, the desired model (1), reflecting the dependence of the total biogas production on the total biomass obtained from poultry, will look like this:

$$\hat{y}_x = 0,049 \cdot x + 149,43 \quad (14)$$

We will determine the reserves laid down in the independent (exogenous) factor. To do this, we calculate the elasticity coefficient using the formula (3).

$$\mathcal{O} = 0,049 \cdot \frac{(32\,610 / 5)}{(2\,342 / 5)} = 0,681 \quad (15)$$

In general, we have the following:

- The sign of the coefficient a_1 in the model (14) corresponds to the real flow of processes in economics and logic
- If the total biomass obtained from birds increases by 1%, the total biogas production will increase by 0.681%.

Thus, based on the results of calculations based on the construction of a two-factor correlation-regression model, the following conclusions can be drawn:

1. The models reflecting the dependence of the total biogas production on the total biomass for cattle, sheep and goats, as well as poultry, correspond to the real flow of processes in the economy and logic
2. With an increase in the total biomass by 1%, the total production of biogas will also increase (for cattle by 1.2147%, sheep and goats by 0.8395%, poultry by 0.681%). Therefore, it is necessary to apply a technology for the production of biogas with a high methane yield.

5. CONCLUSION

Biogas technologies should be installed near agro-industrial complexes, as well as in the territories where animal waste is currently dumped. In this case, there is a possibility of economically justified collection of manure with minimal or no dirt impurities. Analysis of the potential for bioenergy production from agricultural waste showed that the largest volumes of organic waste are produced by cattle breeding, and the smallest – by poultry farming. Agricultural waste will be the main raw material for generating electricity and heat. Calculations based on the construction of a two-factor correlation-regression model also confirmed the dependence of the total production of biogas on the total biomass of animal waste.

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