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Circular economy in agriculture as a vector for energy security strengthening

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Abstract. The article examines the principles of circular economy, its influence on energy security and sustainable development of the country. The possibilities of circular economy implementation in the sector of agriculture are described. The results of circular economy survey are analyzed, main barriers of waste use in agriculture of the Republic of Belarus are detected. The dynamics of livestock and poultry heads number was analyzed and its main trends are found, the forecast for the period of 2022-2030 was made. The assessment of current theoretical and technically available biogas production potential in the Republic of Belarus, as well as the forecast till 2030, is made. The authors evaluated the effect from biogas from agricultural waste, such as waste from livestock and poultry vital activity usage on fuel and energy resource consumption and the indicators of energy security of the Republic of Belarus and Tatarstan.

1 Introduction

Green economy requires a shift towards green energy production based on renewable energy sources to replace fossil fuels, as well as energy conservation and energy efficiency (Figure 1). Obviously, the share of the green economy in world market capitalization is growing, while the fossil fuel sector is shrinking. In particular, as of 2020, green economy accounted for 6% of the market capitalisation of global energy companies by 2020 [1].

Fig. 1. Components of sustainable development and green economy [2].

Circular economy, which is also referred to as the "circular economy" [3], is "a model of production and consumption, including common use (leasing), reuse, improvement, recycling, and disposal of resources and products" (Figure 2) [4]. The theoretically identified model just promotes, it can be found that it is aimed at solving the most serious problems, in particular climate change, biodiversity loss, waste and pollution, probably beyond the thermal pollution that within the circular economy is not discussed explicitly. This is the fundamental difference between the circular economy model and the linear (it can be defined as a standard) model of the economy, which will be considered as a green economy.

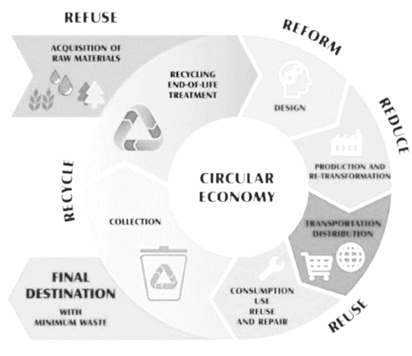

Fig. 2. Circular economy model [5].

The main purpose of this study is to consider the model of the circular economy of its main elements from the standpoint of organizing a closed cycle of food waste processing in agriculture and the possibility of obtaining biogas, as well as forecasting the consumption of electrical energy for all agriculture in general, including energy from biogas.

The scientific significance of this article is the formation of a forecast for the increase in the livestock of farm animals in the Republic of Belarus and the Republic of Tatarstan. Also, it has been established that biogas production is one of the tools for ensuring the country's energy security and implementing mechanisms in the Green Economy.

The practical orientation of a circular economy is to preserve products, materials, equipment and infrastructure for as long as possible [6]. Hence a possible increase in the productivity of energy resources. Energy should trigger the process of increasing the value of waste: either as a new component or as a regenerated resource for continued production. Biogas is an additional source of energy for agriculture.

As a result, natural resources (e.g. compost) should be regenerated. The level of environmental friendliness is increased, additional energy, the level of waste from animal rearing is reduced, and the recycling cycle is increased by converting animal life into energy.

Translated with www.DeepL.com/Translator (free version)The Ellen MacArthur Foundation (EMF) defines circular economy as an industrial economy that is restorative or regenerative in design and purpose [7, 8], which cannot be disagreed with. The circular economy is based on three main components of the economic system – resource providers, waste processors, sources of utility – and promotes the cyclical use of resources to create, supply and consume manufactured products. It is about extending the shelf life of products that are produced within a production system, making them more profitable and sustainable over time. At the moment, the global initiative to promote the circular economy paradigm belongs to the Ellen MacArthur Foundation, which goal is to facilitate the transition to it as an established practice [9].

The theoretical and methodological approaches that form the basis of the circular economy are not fundamentally new, but accumulate the results of scientists' research in the field of industrial ecology, eco-efficiency, resource efficiency, etc. As a concept, it is based on the principles of 9 R[1] and has three key implementation features:

– reserves of natural resources and maintaining a sustainable balance of renewable resources to preserve and maintain an inexhaustible level of natural capital;
– optimization of consumption processes by developing and distributing products, components and materials that meet the highest level of their reuse;
– identification and prevention of negative external effects of current production activities in order to increase the efficiency of economic and ecological systems[2].

Relating to agriculture, this direction is increasingly seen as a promising option for sustainable development, which can be achieved if innovative methods and technologies that minimize the cost of limited resources, stimulate their replacement with renewable ones, prevent losses and stimulate reuse and recycling, which together allows to ensure a qualitative transition from production efficiency to resource use efficiency.

It should be emphasized that the concept of circular economy does not contradict the basic principles of agriculture; moreover, due to the specifics of the industry, it has favorable conditions for implementation. Thus, traditionally, animal waste rich in valuable substances (nitrogen, phosphorus, potassium) was used as a source of fertilizers to improve soil quality; and organic waste from crop and livestock can be used to obtain environmentally friendly energy sources [10].

The problem of food waste management is an important direction in the environmental policy of the country. the stage-by-stage process of production, consumption and processing of food waste by 5 indicators and 25 indicators was studied. found that the level of intensity increases the amount of food waste and increase the duration of the closed cycle of the green economy. Effective management decisions aimed at the formation of a closed cycle will reduce the amount of food waste [34].

A good case in the formation of a closed cycle chain is the production of broilers and neighboring cultivation of feed to feed them. In general, broiler waste at all stages of the ah-ah life cycle is harmful in terms of nitrogen and carbohydrate content. to important decisions is the production of compass protein and the formation of energy [35].

It is necessary to highlight a position regarding the implementation of circular economy projects aimed at decentralizing the processing of food waste and localizing operations within a closed cycle. to This allows, as practice has shown, to mobilely process food waste and receive enough energy in the face of covid restrictions. the limited geographical location and time interval allows optimal timing to receive energy and process food waste [36].

The summation of the closed cycle makes it possible to replace the necessary minerals through the processing of food waste. At the same time, it is

[1] "Refuse" – rejection of excessive use of raw materials; "Recover" – production of energy from materials; "Recycle" – processing and recycling of materials; "Repurpose" – use of the product for other purposes; "Remanufacture" – production of new products from elements of the old; "Refurbish" – updating or restoring old products while keeping most of them unchanged; "Repair" – maintenance and repair of a defective product in order to extend its service life; "Reuse" – reuse of a product that has lost its value for one user, but is necessary for another; "Reduce" – reducing the use of raw materials, aimed at the total elimination of waste production.

[2] Delivering the circular economy: a toolkit for policymakers Delivering the circular economy: a toolkit for policymakers [Electronic resource] / Ellen MacArthur Foundation. [Cowes], 2015. Mode of access: https://www.ellenmacarthurfoundation.org/publications/delivering–the–circular–economy–a–toolkit–for–policymakers. Date of access : 07/08/2020.

important to note the involvement of not only large agricultural organizations, but also personal subsidiary plots that also have food waste, and can also participate in the formation of green economy processes. [37]

Materials and methods. The pathology of this study is based on the data of statistical reporting of livestock production by the Regional State Statistics Committee of the Republic of Tatarstan and the Federal State Statistics Service of the Republic of Belarus. The main parameters for assessing the potential without gas are based on a calculation formula that allows you to estimate the number of livestock and the possible production of biogas. Using the trend method, a biogas production forecast was formed, which in the future will form tools to ensure the energy security of the country as a whole. One of the important directions in the study of the potential for the development of biogas as a tool for obtaining energy is the use of the questionnaire method, which made it possible to identify factors that hinder the implementation of this project. In general, the results of the presented study are of practical importance for the implementation of the biogas production project both in the Republic of Tatarstan and in the Republic of Belarus.

As a result of analising data of circular economy survey conducted by the State Scientific Institution “Research Economic Institute of the Ministry of Economy of the Republic of Belarus” in the second quarter of 2019 by order of the Center for Economic Research Beroc received information about the attitude of agricultural organizations and farms to involvement of waste in reuse [11].

2 Materials and methods

The most common way to handle waste is to use it in their own activities, this was indicated by about 45% of farmers, while burial is acceptable only for a fifth of the respondents (Table 1).

The methods of waste management change significantly depending on the volume of their generation. Thus, 41.2% of farmers whose waste volume does not exceed 10 tons use them in their own activities, and only 5.9% sell them. With an increase in waste generation volume (over 10 tons), the share of waste used in own activities decreases to 30.0%, and the share of waste sold increases to 20.0%. At the same time, the share of buried waste is at the level of 30% and does not depend on the volume of their generation.

The totality of barriers identified by the surveyed agricultural enterprises and their classification according to the rate of waste use is presented in Table 2. The survey data show that agricultural business entities, regardless of their form of ownership and size, identify the same barriers that slows down the use of waste in agriculture. So, technological (lack of processing technologies) and economic (economic inexpediency and lack of resources to focus the production process on the use of secondary raw materials) barriers are the most significant both for large-scale agricultural organizations and for farms (1-3 place in the rating). Lack of sales markets for products from recycled materials and a decrease in the quality of manufactured products when using secondary raw materials have 5-6th place in the rating. At the same time, there are enough examples in the world of the successful use of the principles of the circular economy in agriculture. In particular, in the state of North Carolina (USA), which is a leading producer of poultry and eggs, the problem of poultry farm waste has been solved in a comprehensive manner since 2007. During this period, Georgia Renewable Power (GRP) created several biomass power plants that process poultry waste by mixing it with wood chips to generate electricity. In May 2017, Veolia, a company with extensive experience in implementing circular projects, was engaged to optimize technological solutions, which significantly increased the economic efficiency of waste processing. The plant currently processes up to 285,000 metric tons of poultry waste annually and has a capacity of 25 MW. Ambitious goals have been set to ensure 100% recycling of poultry waste [12].

Based on current trends analysis in order to assess the national economy sectors future needs in energy resources, the State Scientific and Production Institution “Institute of Energy of the National Academy of Sciences of Belarus” developed optimistic and pessimistic scenarios for electricity consumption in the agricultural sector of the Republic of Belarus. Forecasting long-term trends in electricity consumption in the agricultural sector of the Republic of Belarus is determined by the influence of a number of factors, the main of which include: the structure of the economy and its structural transformation; economic growth rates; rate of technological progress. Thus, the main indicators in forecasts preparation were: GDP growth rate; the rate of change in electrical and heat capacity.

According to scenario assumptions, it is assumed that the structure of the Belarusian economy will remain unchanged starting from 2030. The share of agricultural, forestry and fisheries sector in GDP from 2030 will be 6% (Fig. 3).

Analyzing the results of the forecasts presented in Fig. 3, we can conclude that according to the pessimistic scenario, electricity consumption in agriculture will increase by 1.36 times in 2050 compared to 2020, and by 1.53 times according to the optimistic scenario. The difference in electricity consumption according to the scenarios in 2050 will reach 314 million kWh and it can be covered through the introduction of circular economy principles in this sector, in part, the use of agricultural waste for the production of electricity.

Table 1. Attitudes towards the waste reuse in farms, depending on the amount of waste generated.

Name of indicator	All respondents	volume of generated waste		
		less than 1 ton	1–10 tons	more than 1 ton
General characteristics of a typical farm participating in the survey				
Average number of employees for 2018, people	6	5	6	10
Annual volume of generated waste, tons	4.4	less than 1 ton	1–10 tons	more than 1 ton
Distribution of answers to the question "How do you handle industrial waste?", %				
– use in our own activities	44.8	69.2	41.2	30.0
– transfer for processing	10.3	0.0	14.7	0.0
– sell	12.1	23.1	5.9	20.0
– bury / transfer for burial (neutralization)	22.4	0.0	29.4	30.0
– transfer to storage objects	10.4	7.7	8.8	20.0
Distribution of answers to the question "Does your company use third-party secondary raw materials?", %				
yes, for energy production	1.6	3.4	0.0	0.0
yes, in production	6.5	6.9	8.3	0.0
yes, in servicing the main activities of the economy	9.7	3.4	16.7	20.0
no, do not use	82.2	86.3	75.0	80.0

Note: The total selection includes 64 respondents.

Table 2. Rating of barriers to the use of waste in agriculture.

Barrier	Wastevolume								
	Agricultural organizations					Farms			
	All respon dents	Volume of generated waste				All respondents	Volume of generated waste		
		less than 1 ton	1–20 tons	21–50 tons	more than 50 tons		less than 1 ton	1–10 tons	more than 10 tons
Economic inexpediency	2	2	3	1	2	2	1	2	1
Lack of processing technologies	1	1	1	1	1	1	2	1	1
Lack of resources to orient production process for the use of secondary raw materials	3	n. b.	2	2	3	3	3	4	n. b.
Decrease in quality of products when using secondary raw materials	6	Nb	4	n. b.	Nb	6	n. b.	n. b.	1
Lack of markets for recycled products	5	n. b.	n. b.	3	5	5	n. b.	5	1
Lack of information on the volumes of available third-party secondary raw materials	8	n. b.	n. b.	n. b.	6	4	4	5	1
Lack of access to third-party recycled materials	6	Nb	5	n. b.	6	5	4	5	n. b.
Lack of necessary legislative framework regulating relations in the field of waste	4	n. b.	4	n. b.	4	3	3	3	n. b.
Other	7	Nb	4	n. b.	Nb	Nb	n. b.	n. b.	n. b.

Note: the barriers are ranked according to the "traffic light" principle: the red zone is the most important (the most popular answers, 1-2 places in the rating); yellow zone - quite significant (located in the upper part of the rating, 3-4 positions in terms of popularity); green zone - not very significant (5th-9th place in the rating), nb - not identified by respondents as a barrier.

1	2	3	4	5	6	7	8	9
great influence								least influence

Source: own calculations based on survey data of the State Scientific Institution “Research Economic Institute of the Ministry of Economy of the Republic of Belarus”.

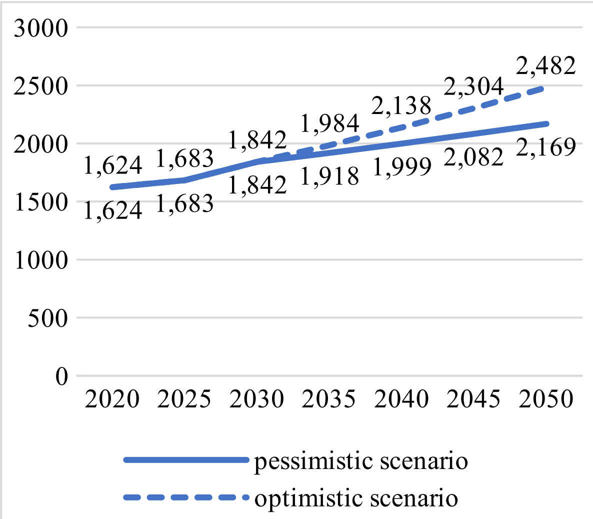

Fig. 3. Forecast of electricity consumption in the agricultural sector of the Republic of Belarus until 2050, million kWh.

3 Results and discussion

Electricity production from biogas in the world has doubled over ten years: from 46.3 thousand GWh in 2010 to 91.8 thousand GWh in 2019, while global electricity consumption increased over the same period by a quarter and by 2019 amounted to 25.0 million GWh [13, 14]. 67% of all electricity produced from biogas was obtained in Europe, the leader in production is Germany, where more than a third of the world's energy production from biomass is generated. Among other countries actively implementing biogas technologies are Italy, China, France, Czech Republic, Thailand, Turkey. The cost of energy production from biogas in Germany is 0.07-0.11 EUR/kWh, while the cost of energy from natural gas it ranges from 0.09 to 0.20 EUR/kWh [15]. It should be noted that in both cases the fuel component is excluded from the cost due to free substrate in many cases for the operation of a biogas plant and changing price of natural gas. The payback period for biogas plants, according to studies [16-19], does not exceed 10 years.

On the territory of the Republic of Belarus there is a large number of livestock complexes, which allows us to consider the waste products of livestock and poultry kept there as a reliable raw material base for biogas production.

In the Energy Potential Development Strategy of the Republic of Belarus, approved by the Decree of the Council of Ministers of the Republic of Belarus on August 9, 2010 No. 1180, the volume of biogas production is estimated at 503.7 million m3, which is equivalent to 433.2 thousand tons of coal equivalent [20].

According to the National Program for the Development of Local and Renewable Energy Sources for 2011–2015, approved by the Decree of the Council of Ministers of the Republic of Belarus on May 10, 2011 No. 586, the total biogas production potential only at cattle, pigs and poultry farms and complexes is 4158.5 million m3, which is equivalent to 3.18 million tce ; however, use of installations with electric power of more than 150 kW, which is feasible only at large farms, the effect of biogas is reduced to the replacement of 635.5 thousand tce [21]. In a study of Belarusian scientists [22], the theoretical potential of biogas in 2011 is estimated at 1603 million m3, which is equivalent to 1259 thousand tce .

Considering the significant differences in data on the existing potential of biogas, as well as the livestock and poultry, it is advisable to assess the biogas potential in the Republic of Belarus at the present time, as well as build a forecast for the coming years.

3.1 Dynamics and forecast of the livestock and poultry number at farm in the Republic of Belarus

As of the beginning of 2021, the number of cattle in farms of all categories in the Republic of Belarus reached 4292 thousand heads, pigs – 2872 thousand heads, sheep and goats - 148 thousand heads, horses – 34 thousand heads, poultry – 48 million heads [23]. The dynamics of the most numerous types of livestock and poultry in the farms of the Republic of Belarus is shown on Figure 4.

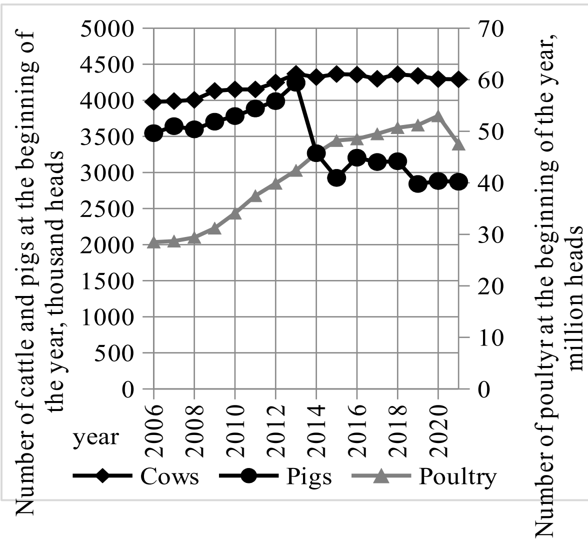

Fig.4. Dynamics of cows, pigs and poultry number in the Republic of Belarus. Source: Own development based on [24].

The increase in the number of cows in the period from 2007 to 2013 is associated with the development of not only meat, but also the dairy industry. During the specified period, against the background of a general decrease in the share of household spending on food, spending on dairy products has the highest growth compared to previous years (spending growth by 22%

from 2006 to 2013) compared to other categories of food products with a similar consumer price index [25, 26]. From 2013 to 2021, the number of cows remains relatively stable with fluctuations of no more than 1% of the average value for the specified period. This fact can be interpreted as finding a certain balance point between production, consumption, imports and exports, as well as making an assumption about stability in the coming years in the absence of significant external or internal unpredictable disturbances.

Until 2013, there was a clear increase in the number of pigs in the Republic of Belarus. The sharp decline in the number of pigs that took place in 2014 was caused with the aggravation of the epidemiological situation associated with recommendations African swine fever and massive for pigs' slaughter [27, 28]. Thereafter, the population stabilized. The lack of indicator tendency to the values of the previous period can be explained by the partial compensation of pork by meat of other livestock and poultry, as well as by the reduction in the share of private entrepreneurship in this industry and the share of exports. Since 2014, some stabilization in the number of pigs can be noted, despite the existing fluctuations.

The increase in the number of poultry in the Republic of Belarus has been observed since 2008. The production of poultry meat is more profitable than the production of beef or pork due to the lower cost and a shorter technological cycle, which is reflected in the cost of products for sale. For this reason, even during periods of crisis, the demand for poultry meat does not fall [25]. Over the period from 2015 to 2020, the growth in the number of poultries decreased slightly, but still took place. At the same time, a sharp drop to 48 million head can be observed in 2021.

If we consider in comparison with the Republic of Tatarstan, Russia (Table 3).

Table 3. Number of cattle in dynamics in the Republic of Tatarstan, thousand units.

Animal species	2010	2012	2015	2019	2020
Number of cattle	1124.6	1076	1033.6	707.8	689
Cows	420	403.2	343.60	235.3	229.05
Pigs	709.6	658.9	670.56	459.2	447.0
Sheep, goats	403	372.1	83.67	57.3	55.77
Poultry, million heads	34	31	24.53	16.8	16.35
Horses	36	32	27.59	18.9	18.39

In the agriculture of the Republic of Tatarstan there is no clearly defined specialization in the production of any product. It is approximately equally distributed between crop production (49.0% of all agricultural production in the region in value terms) and animal husbandry (51.0%). The animal husbandry of Tatarstan is characterized by high volumes of production of beef, milk, eggs, poultry meat, lamb and goat meat. Pork production, on the contrary, has been declining over the past few years, although it still exceeds the figures of 10, 15 years ago. The number of pigs in all categories of farms in the Republic of Tatarstan at the end of 2015 amounted to 481.2 thousand heads. This is 2.2% of the total number of pigs in Russia (11th place in the ranking of regions). Pork production in the Republic of Tatarstan in all categories of farms in 2015 amounted to 94.4 thousand tons in live weight (73.4 thousand tons in terms of slaughter weight). For comparison, in 2010 pork production in Tatarstan amounted to 100.2 thousand tons in live weight (75.7 thousand tons in terms of slaughter weight). At the end of 2015, the republic is in 11th place in terms of pork production (2.4% of the total pork production in the Russian Federation).

The agriculture of Tatarstan is largely based on cattle breeding. The cattle breeding of Tatarstan provides the region with high positions in the production of beef and milk in the Russian Federation. In contrast to the all-Russian trends, characterized by a significant decrease in beef production, in Tatarstan, the production of this type of meat is relatively stable - in 2015 it was at the level of a decade ago. In general, in the Russian Federation over 10 years it decreased by 10.1%.

As of the end of 2015, in terms of the total number of cattle, Tatarstan is in 2nd place in Russia (second only to the Republic of Bashkortostan) - 1,033.7 thousand heads (5.5% of the total number of cattle in the Russian Federation). Including the number of cows, there were 366.7 thousand heads (4.4% in the all-Russian number of cows, 3rd place in the Russian Federation).

Beef production in Tatarstan in 2015 was at the level of 150.2 thousand tons in live weight (85.4 thousand tons in terms of slaughter weight). For 5 years, production decreased by 9.4% or by 15.6 thousand tons in live weight. At the end of 2015, the republic took 2nd place in the ranking of beef producing regions. share in general volume production beef in country amounted to 5.2%.

To determine the number of livestock and poultry, as well as their percentage grouping across farms of various types in the coming years, forecasting methods based on the trend model construction were used: regression model and forecasting method based on an average value.

When choosing a method for livestock and poultry number forecasting, the number of which fluctuated in recent years, but remained close to the average value in these years, the average value method was applied (Table 4). The regression model was built for those kinds where an increase or decrease was observed in previous years (Table 5).

Table 4. Forecast of livestock number in the Republic of Belarus (cows, pigs, sheep and goats).

Kind of livestock	Number, thousand heads in a year	
	2021 facts	2022–2030
Cows	1485	1506
Calves	2807	2822

Pigs	2872	3036
Sheep, goats	148	148

Also, a regression model was built to forecast the share of livestock and poultry at farms of agricultural organizations (Table 6, 7).

3.2 Biogas production potential determination and forecasting

Based on the data on the biogas production volume from one animal or bird, proposed in [22, 29, 30], we will evaluate the theoretical and technically available potential [31] of biogas production in the Republic of Belarus, obtained from the waste products of livestock and poultry.

When calculating, we take into account a number of features.

1. As known, for the operation of a biogas plant, a certain amount of thermal energy is required to heat the raw materials and maintain the set temperature in the digesters. According to the set out in [22], one fifth of the energy produced recommendations is spent on the own needs of a biogas plant.

Table 5. Forecast of the livestock and poultry number in the Republic of Belarus (horses, poultry).

Kind of livestock or poultry	number									
	2021 facts	2022	2023	2024	2025	2026	2027	2028	2029	2030
Horses, thousand heads	34	29	26	23	twenty	eighteen	16	fourteen	12	eleven
Poultry, million heads	48	51	52	52	52	52	52	52	53	53

Table 6. Forecast of livestock and poultry share kept in farms of large agricultural organizations in the Republic of Belarus.

Kind of livestock or poultry	Share of livestock and poultry kept in farms of large agricultural organizations, %									
	2021 facts	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cows	97.9	98.0	98.0	98.1	98.2	98.2	98.3	98.3	98.4	98.4
Calves	96.1	96.2	96.3	96.5	96.7	96.8	96.9	97.1	97.2	97.3
Pigs	89.1	89.3	90.0	90.6	91.3	91.9	92.6	93.3	93.9	94.6
Sheep, goats	8.1	8.8	9.1	9.4	9.7	10.0	10.3	10.5	10.8	11.1
Horses	40.0	40.3	40.5	40.7	40.9	41.1	41.3	41.5	41.6	41.8
Poultry	90.8	91.1	91.2	91.4	91.6	91.7	91.8	91.9	92.0	92.1

Table 7. Forecast of the number of farm animals, in the Republic of Tatarstan.

Kind of livestock or poultry	Share of livestock and poultry kept in farms of large agricultural organizations									
	2021 facts	2022	2023	2024	2025	2026	2027	2028	2029	2030
Cows	198.3	200.28	202.29	204.31	206.35	208.42	210.50	212.60	214.73	216.88
Pigs	422.2	426.42	430.69	434.99	439.34	443.74	448.17	452.66	457.18	461.75
Sheep, goats	53	53.53	54.07	54.61	55.15	55.70	56.26	56.82	57.39	57.97
Bird, million units	fifteen	15.15	15.30	15.45	15.61	15.77	15.92	16.08	16.24	16.41
Horses	17	17.17	17.34	17.52	17.69	17.87	18.05	18.23	18.41	18.59

Let's make a forecast for the number of cattle in the Republic of Tatarstan until 2030. At the same time, it is important to take into account that there has been a downward trend in the number of livestock since 2010. At the same time, a number of programs are being implemented in the Republic aimed at supporting agricultural producers to increase the number of livestock. Therefore, within the framework of an optimistic forecast, this figure is planned not to decrease, to have a small increase or remain on the same level .

2. Despite the presence of low-capacity biogas plants designed to process the waste products of several heads of livestock [32, 33], the most stable and efficient operation of plants takes place at complexes with a large number of livestock kept. In this regard, when determining the theoretical potential for obtaining biogas in the country, the entire number of livestock and poultry is taken into account, when determining the technically available - only the part kept at large agricultural organizations.

3. Manure removal systems do not always allow the use of the entire generated waste products volume for biogas production. In this connection, it becomes necessary to use corrective coefficients:

k_1 = 0.7 – coefficient that takes into account the impossibility of collecting and using cows manure for biogas production (a similar coefficient will be applied to horses, sheep and goats);

k_2 = 0.8 – coefficient taking into account the specificity of using a pig manure water flushing system;

k_3 = 1.0 – coefficient that takes into account the specificity of the use of the poultry manure collection system [20].

To calculate the theoretical potential of biogas production, it is proposed to use the formula obtained on the basis of the study [22]:

$$P_{theoretical} = (1 - 0.2) \cdot N \cdot g \quad (1)$$

where 0.2 – share of energy for own needs; N – number of livestock or poultry of one kind; g – estimated biogas production per head of livestock or poultry per year.

The technically available potential requires taking into account the specifics of the disposal of waste and the proportion of livestock and poultry kept at the large farms of agricultural organizations, and is calculated with the formula:

$$P_{technical} = \frac{P_{theoretical} \cdot k_x \cdot \varphi}{100} \quad (2)$$

where k_x – coefficient that takes into account the removal of waste and is specific to x animal kind; φ – share of livestock and poultry kept at large agricultural organizations.

The potential of biogas production from livestock and poultry waste products, taking into account their actual number at the beginning of 2021, is presented in Table 8.

Tables 9 and 10 show the forecast of the theoretical and technically available potential of biogas production from livestock and poultry waste product for the period of 2022-2030.

Table 8. Potential of biogas production from livestock and poultry waste products at the beginning of 2021.

Type of livestock or poultry	Biogas output per head	Biogas output		Theoretical potential		Technically available potential	
	m^3/year	million m^3/year	thousand tce/year	million m3/year	thousand tce/year	million m^3/year	thousand tce/year
Cows	450–548	668–813	528–642	535–650	422–514	359–437	284–345
Calves, heifers	315–330	884–926	699–732	707–741	559–585	484–507	383–401
Pigs	73–1010	210–314	166–248	168–252	133–199	118–178	94–140
Sheep, goats	120–150	18–22	14–17.5	14–18	11.2–14	0.8–1	0.6–0.8
Horses	300–350	10–12	8.1–9.4	8.2–9.5	6.4–7.5	2.3–2.7	1.8–2.1
Poultry	5.5–6.2	260–295	205–233	208–236	164–186	189–215	149–170
Total:	–	2050–2383	1620–1883	1640–1906	1296–1506	1154–1340	917–1059

Table 9. Forecast of theoretically and technically available biogas production from livestock and poultry waste products potential in Republic Belarus.

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
theoretical potential (min)	1327	1327	1327	1328	1328	1328	1328	1328	1329
theoretical potential (max)	1545	1545	1545	1546	1546	1546	1546	1546	1547
technically available potential (min)	938	941	943	945	947	949	951	953	955
technically available potential (max)	1092	1095	1098	1101	1103	1106	1108	1111	1113

Table 10. The potential for obtaining biogas from the waste of agricultural animals, taking into account their actual livestock at the beginning of 2021 in the Republic of Tatarstan.

Kind of animal	Biogas output per head	Biogas output, total		Theoretical potential		Technically possible potential	
	m^3/year	million m^3/year	thousand tce/ year	million m^3/year	thousand tce/ year	million m^3/year	thousand tce/year
Cows	450–547.5	56–87	54–82	56.2–87.3	54.56–82	359–437	283.5–344.9
Pigs	315–330	79–82	77–79	79.3–82.4	77–79.3	484–507	382.6–400.8
Sheep and goats	73–109.5	19–29	17–27	19.5–29.2	17–27.2	118–178	93.6–140.4
Bird , million heads	120–150	9–11	7–9	9.67–11.4	7–9.3	0.8–1	0.6–0.8
Horses	300–350	2–4	0.9–1.2	2.67–4.1	0.9–1.2	2.3–2.7	1.8–2.1
Total:	–	887–992	778–889	887.45–992.5	778–889.4	1154–1340	911.6–1058.5

4 Conclusion

Based on the study, the following conclusions can be drawn in Republic Belarus:

– the theoretical potential at the beginning of 2021 is 1640-1906 million m3/year, which is equivalent to 1296–1506 thousand toe/year and allows to replace 1126–1309 million m3 of natural gas annually; the technically available potential is estimated at 1154–1340 million m3/year, which is equivalent to 912–1059 thousand tce /year and allows to replace 794-922 million m^3 of natural gas annually;

– by 2030, the theoretical potential for biogas production will increase slightly: up to 1682–1958 million m3/year, which is equivalent to 1329–1547 thousand tce /year or the replacement of 1155–1345 million m3 of natural gas; technically available potential increases to 1209–1409 million m^3/year, which is equal to replacement of 955–1113 thousand tce /year or 830–968 million m3 of natural gas.

– full use of technically available potential of biogas from livestock and poultry waste products will replace 3–4% of fuel and energy resources consumed in the Republic of Belarus or 5–6% of the fuel and energy resources spent in the country to produce heat and electricity.

– in addition, there will be an increase in the energy security of the country, which can be numerically expressed in values increase of the indicators of the block “Energy independence”: No. 1 “The ratio of primary energy production to the gross consumption of fuel and energy resources” and No. 2 “The ratio of primary energy production from renewable energy sources to gross consumption of fuel and energy resources”, each by 3–4%, and a decrease in the indicator value of the block “Diversification of suppliers and types of energy resources” No 4 “Share of the dominant type of fuel in gross consumption of fuel and energy resources” also by 3–4% by 2030.

As for Tatarstan (Table 10), there is a positive trend here, and the theoretical potential of biogas from cows is 54 million cubic meters a year, from pigs – 77, sheep and goats – 17, birds – 9 horses – 1.2. This is a good tool for developing other energy resources in rural areas. In addition, it is a good tool for reducing environmental friendliness and organizing a closed-loop green economy. This resource of the Republic can be fully used. Here it is important to take into account the increase in livestock. And the increase in energy consumption due to mechanization, automation of machinery and equipment in rural areas. in general, within the framework of the study, all the objectives were achieved; in the framework of subsequent studies, other sources of renewable energy will be considered.

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