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The scientific monograph presents the global trends and prospects of socio-economic development of Ukraine. General questions of economics and enterprise management, regional economics, marketing, modern management, general pedagogy and history of pedagogy, theory and methods of vocational education, general questions of historical sciences, and so on are considered. The publication is intended for scientists, educators, graduate and undergraduate students, as well as a general audience.

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ECOLOGIZATION OF AGRICULTURAL PRODUCTION BASED ON THE USE OF WASTE-FREE TECHNOLOGIES TO ENSURE ENERGY AUTONOMY OF AIC

Valeriia Vovk[1]
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Abstract. Global climate change due to the greenhouse effect has become a major international and political issue. Carbon dioxide is recognized as one of the main factors enhancing the greenhouse effect. Other known greenhouse gases together account for about half of global warming. Excess in the atmosphere of greenhouse gases and aerosols, solar radiation and the properties of the earth's surface change the energy balance of the climate system. Agriculture is a significant source of greenhouse gas emissions, as livestock and crop production are associated with emissions of carbon dioxide, methane and nitrous oxide. According to reports of emissions that governments regularly submit to the Secretariat of the United Nations Framework Convention on Climate Change, agriculture accounts for about 15% of global greenhouse gas emissions. On the other hand, greenhouse gases change the climate and thus affect agricultural production. At the same time, the share of agriculture in world GDP is about 4%, which indicates that the carbon intensity of agriculture (emissions per unit of output) is quite large. Urgency of ecologization of agriculture of Ukraine is conditioned by worsening of the ecological state of the natural resources, related to the agricultural production, decline of fertility of soils and product quality, by the increase of complex ecologically-destructive influence on the environment. Ecological agriculture is economically advantageous direction of activity with the high level of profitability comparatively with traditional technologies of production. The main direction of agricultural development should be the ecologization of all production processes,

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which led to the interest and conduct of this study. *Purpose*. The purpose of the research is to substantiate the theoretical and applied principles of ecologization of agricultural production based on the use of waste-free technologies to ensure energy autonomy of agriculture. The subject of the research is theoretical-methodical and practical aspects of using waste-free technologies for ecologization of agricultural production and ensuring energy autonomy of AIC. *Methodology*. The research used the following scientific methods: monographic (in studying the theoretical provisions of ecologization of agricultural production and use of waste-free technologies), statistical (in analyzing the state of agriculture and the use of waste-free technologies for renewable energy, reducing fossil fuel consumption and how consequence, ecologization of agricultural production) computational and constructive (in substantiating the management practice of resource conservation in agricultural development on the principles of waste-free production), various methods of economic and statistical method (statistical observation, comparison, tabular, graphical) – in the development of visual illustrations; abstract-logical – to summarize research results and formulate research conclusions. *Practical implications*. The impact of biogas production from livestock waste in Ukraine on the ecologization of AIC is analyzed. Measures have been proposed to promote the development of waste-free biogas technologies in Ukraine to ensure energy autonomy of the agro-industrial complex. *Value/originality*. The economic efficiency of replacing natural gas with biogas formed from agrobiomass is determined. The author's bioenergy model of biogas production from agricultural waste is proposed. The analysis of the advantages of biogas production from agrobiomass for ecologization of agricultural production was further developed. The enterprises of Vinnytsia region, which have the largest capacities of biogas production from agrobiomass, are characterized. The study is based on the tasks of applied research on the topic: "Development of scientific and technical support for energy autonomy of the agro-industrial complex based on environmentally efficient use of agrobiomass for biofuel production", state registration number 0122U000844.

1. Introduction

Today, the development of the world economy has been accompanied by numerous negative phenomena, among which the key one was

environmental problems in agriculture, related to irrational use of nature, degradation and pollution of land, water and air, biodiversity loss and more. The answer to the above challenges was the development of the concept of sustainable development, which is based on the harmonization of three main areas – economic, social and environmental.

The main idea of the concept of sustainable development is to preserve the environment and natural resources for future generations, which should be implemented not through traditional methods of environmental protection, but through changes in the model of civilizational development. It aims to reduce the anthropogenic load on the environment in such a way that the pressure on it is not higher than its potential and reproductive capacity. Therefore, the desire for economic growth was replaced by the desire to promote socio-economic development of society while preserving the natural foundations of life.

The intensification of agricultural production in many countries around the world has led to significant negative and even crisis phenomena that have affected almost all forms of living organisms. Excessive chemicalization of agricultural production processes, unlimited use of mineral fertilizers, active use of GMOs in crop and livestock production and other abuses aimed at maximizing profits have led to significant harmful effects on the natural resources and the environment. Society has a crucial task – not only to reduce the negative impact of intensive agricultural practices on human health and the environment, but also to develop and implement innovative agricultural practices that would ensure the balanced development of agriculture, society and nature in general.

That is why in the concept of sustainable development the decisive role is given to the ecologization of agricultural production, which provides a harmonious combination of the created environment of human life and maintaining the quality of the environment, both for present and future generations.

The urgency of ecologization of agricultural production is due to the sharp deterioration of the ecological state of natural resources associated with agricultural production, reducing soil fertility and quality of agricultural products, increasing the complex ecological and destructive impact on the environment. Organic food has a positive effect on the environment and human health. Secondly, as international experience shows, organic

agriculture is a cost-effective area of activity with a higher level of income than traditional production.

2. Analysis of recent research and publications

The idea of ecologization of agriculture is studied by such economists as A. Andreichenko, O. Bondar, A. Burliai, I. Honcharuk, T. Yemchyk (Honcharuk), G. Kaletnik, I. Kyrylenko, N. Pryshlyak, D. Tokarchuk, O. Khodakivska, O. Shkuratov, O. Shpykulyak, O. Shpychak and others.

Concerning ecologization of agriculture Burlyay A. means a managed process of consistent implementation of technical, technological, economic, managerial, organizational, innovative and other measures to form a sustainable socio-ecological-production system in the process of agricultural activities and agricultural production that promote environmental management, conservation and improving the quality of the environment at the local, regional or global levels [4, p. 45].

Honcharuk I. notes that the ecologization of agricultural production should be understood as the gradual spread of environmental priorities in production activities, increasing environmental education and awareness of management, the gradual penetration of environmental innovations in production, environmental modernization of production [5].

Khodakivska O. noted quite rightly that ecologization of agricultural production is a system of national, sectoral and regional measures aimed at introducing into agricultural production of qualitatively new, environmentally friendly types of equipment, technologies and organization of material production, methods and techniques of agricultural and agro-industrial complexes for rational use of natural resources, their preservation, reproduction and maintenance of dynamic ecological balance in the environment, production of safe food for human health and harmonization of relations in the system "man – society – nature" [6].

Tereshchenko V. believe that the ecologization of agricultural production is a purposeful process of introduction of ecological and economic management methods in agricultural practice in order to ensure ecological balance in the natural environment, preservation of landscape and biological diversity, reproduction of natural resources and guarantees of production of environmentally friendly products and raw materials [8, p. 78].

3. Assessment of ecological and destructive impact of agriculture on the environment

The main factors of ecological and destructive impact of agriculture on the environment are soil, water, air and biodiversity. In Ukraine, about 72% of land resources have been mastered at the permissible norm of 60-65% of the total area, plowing reaches 58% at the norm of 40%; agriculture accounts for more than 10% of greenhouse gas emissions from human activities; almost all surface and a significant part of groundwater resources, especially in areas of powerful agricultural complexes, are experiencing anthropogenic impact, manifested in pollution, depletion and degradation of these facilities; the problem of biodiversity loss is growing rapidly [2, p. 58].

Organic waste and waste with high content of organic matter in unorganized discharges and spontaneous storage are the most dangerous to the environment. The main factor of their negative impact is the processes of decay and other biochemical transformations, which are accompanied by intensive accumulation and migration into adjacent environments of very toxic, often well-soluble organic products.

The structure of total greenhouse gas emissions from the agricultural sector of Ukraine in 2019 is shown in Figure 1.

The peculiarity of the threatening situation in the field of agricultural waste management in Ukraine is the large volume of their formation in the absence of proper infrastructure for their management and environmentally friendly technologies for the use of waste as raw material. The most hazardous agricultural wastes are livestock wastes, which account for 9% of global CO_2 emissions, 35-40% of global methane emissions, and 64% of global nitrous oxide emissions. According to the National Inventory of Anthropogenic Greenhouse Gas Emissions [10], the second largest producer of greenhouse gases in Ukraine animal excrement: pig-breeding – 46.0%, livestock – 30.0%, poultry – 20.0%, other animal species account for 4% of emissions. Therefore, the problem of environmental challenges in the livestock sector is considered from the standpoint of reducing the negative impact of the industry on the environment, and globalization and the pace of climate change require new approaches to addressing the disposal and recycling of livestock waste.

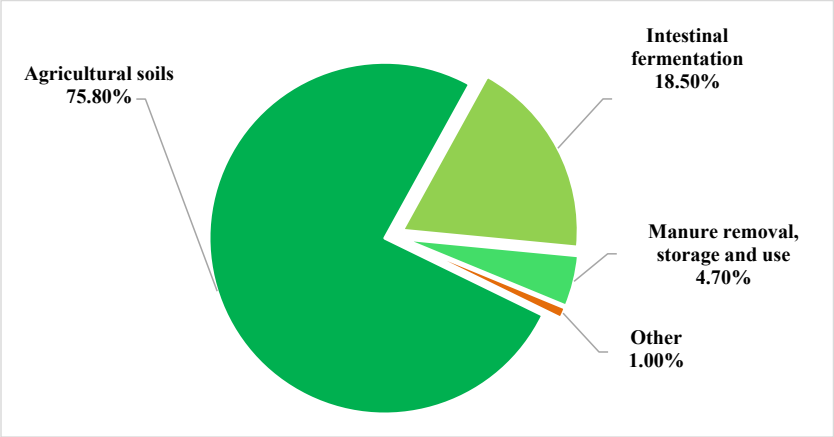

Figure 1. Structure of total greenhouse gas emissions from the agricultural sector of Ukraine in 2019, %

Source: formed by the authors according to the data [9, p. 152]

Drains from livestock complexes are doubly dangerous because they cause both chemical and biological contamination (by microorganisms). Moreover, they pollute the soil directly, as well as water and air. Up to 605 kg of dust, 14.4 kg of ammonia and 83.4 billion microorganisms enter the air from one pig farm for 10-40 thousand animals in 1 hour.

The livestock industry in Ukraine is declining every year, which has a positive effect on reducing greenhouse gas emissions, but at the same time leads to a significant reduction in humus stocks in soils and weakening the crop industry. According to the Institute of Soil Protection of Ukraine, a century ago Ukrainian soil contained an average of 4-6% humus, and now – 3.2%. If less than 2.5% of humus remains in the soil, it will no longer be chernozem (black earth). Every 5 years the soils of Ukraine lose on average 0.05% of humus. In monetary terms, over twenty years it amounted to about UAH 450 billion, and annually it is more than UAH 20 billion. In 2021, the number of cattle in Ukraine was 2.87 million; 5.88 million pigs and 200.7 million poultry. Every year the livestock industry in Ukraine is declining, as evidenced by the data in table. 1.

Table 1

Formation of livestock by-products (pus, droppings) in Ukraine, 2017–2020

Type of raw material	Yield of manure or manure, t / animal place / year	Years									
		2017		2018		2019		2020		2021	
		million heads	amount of waste, million tons	million heads	amount of waste, million tons	million heads	amount of waste, million tons	million heads	amount of waste, million tons	million heads	amount of waste, million tons
Cattle manure	18,00	3.68	66.4	3.53	63.54	3.33	59.94	3.10	55.80	2.87	51.66
Pig manure	3,60	6.67	24.01	6.11	22.00	6.03	21.71	5.73	20.63	5.88	21.18
Bird droppings	7.50 / 100	201.7	15.13	204.8	15.36	211.7	15.88	220.5	16.54	200.7	15.05

Source: formed by the authors on the basis of data [11] and own calculations

Comprehensively solve the problem of environmental pollution by methane and nitrogen emissions from livestock waste possible through the introduction of innovative environmentally friendly technologies for the disposal of agricultural waste, including biogas plants. Such installations are widely used in European agricultural and industrial enterprises.

4. The use of waste-free technologies in agricultural production to ensure energy autonomy of agriculture

The introduction of waste-free technologies in agricultural enterprises and the production of biofuels such as biodiesel, bioethanol and biogas are one of the alternatives to traditional fuels in agriculture. The production of biofuels contributes not only to the energy autonomy of the agro-industrial complex, but also to the reduction of a number of environmental threats.

In our opinion, the most promising area of waste-free technologies of agricultural production is the production of biogas from agricultural waste. Due to the rapidly growing

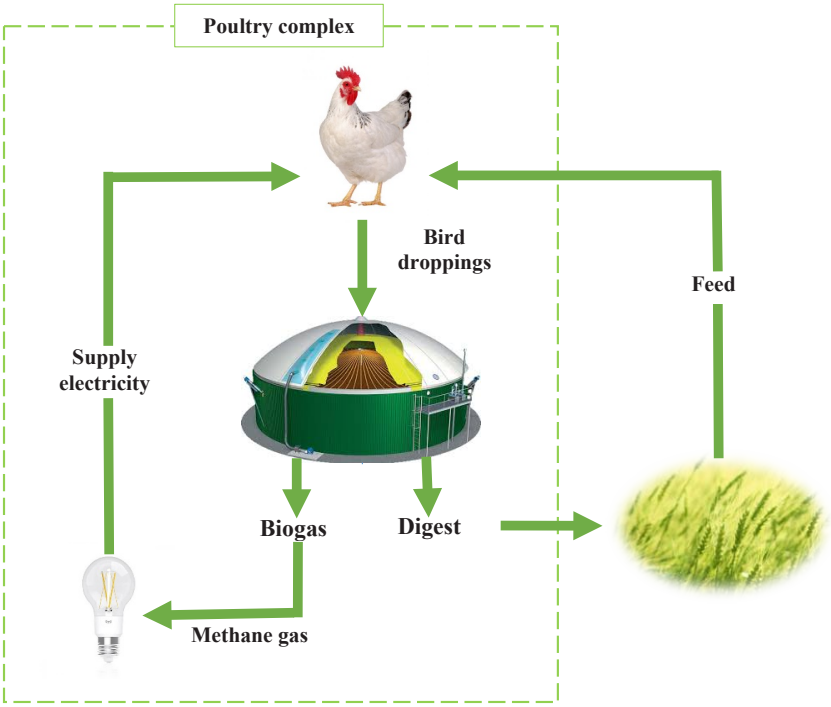

Figure 2. Advantages of introduction of waste-free technologies for utilization of agricultural waste (on an example of a poultry complex)

Source: created by the authors

amount of organic waste, biogas production solves the problem of waste disposal, thereby preventing emissions of methane and other greenhouse gases into the environment, reduces the use of chemical fertilizers and prevents contamination of soil and subsoil water.

In Figure 2 the author's vision of the advantages of the process of biogas production from agricultural waste on the example of the functioning of the poultry complex and biogas production from bird droppings is given.

The common practice of storing industrial waste (manure) in open pits or lagoons leads to environmental degradation in the surrounding areas. Disposal of manure in large quantities is expensive, and fines for violating sanitary norms are also large. Obtaining biogas from manure not only solves

this problem, but at the same time is a way to generate additional income from the sale of heat and electricity. To ensure stable and uninterrupted operation of the biogas plant, it is better to provide for the possibility of biogas production from mixed raw materials – crop and livestock waste. Thus, a biogas plant running on agricultural waste will be evenly loaded throughout the year, and biogas production will be a manageable and predictable process.

In addition, the use of waste-free technologies in agricultural production will not only reduce the ecologically destructive impact on the environment, but also change the structure of final energy consumption in favor of renewable energy sources and ensure energy autonomy of agriculture. According to the State Statistics Service of Ukraine, in 2020 the largest share in the structure of energy consumption of Ukraine's agro-industrial complex is occupied by oil products (1060 thousand tons AD), electricity (325 thousand tons AD), heat (174 thousand tons AD) and natural gas (122 thousand tons AD). Consumption of energy produced from coal and peat (5 thousand tons AD) and biofuels and waste (28 thousand tons AD) is a small share (Table 2) [11].

Biogas derived from biomass is used as a fuel and is not harmful to the environment, as it does not cause additional greenhouse gas emissions and reduces the amount of organic waste. Unlike wind energy and solar radiation, biogas can be produced regardless of climatic and weather conditions. Unlike fossil energy sources, biogas in Ukraine has a renewable potential of 3.2 billion m^2, which remains unused [12].

Due to the fact that the energy value of different agricultural wastes is not the same, the output of gas from 1 ton of it also differs. Manure from livestock complexes is mainly used to produce biogas. It is known that 1 goal. cattle on average per day gives 45 kg of manure, from which you can produce 2.5 m^3 of biogas, the output of manure and gas from 1 goal. pigs – 6.5 kg and 0.3 m^3, respectively, poultry – 0.137 kg and 0.02 m^3. At the same time, its cost is 15-20 euros per 1000 m^3.

In Figure 3 shows the volume of biogas production using a variety of raw materials. When choosing biogas plants, keep in mind that they can be applied simultaneously to different raw materials and use different methods depending on the moisture content. At the same time, special enzymes are used to increase the efficiency of biogas production and reduce equipment recovery time.

Table 2

Final energy consumption of the agro-industrial complex of Ukraine for 2017–2020

№	Types of fuel and energy	Years							
		2017		2018		2019		2020	
		Ktoe	%	Ktoe	%	Ktoe	%	Ktoe	%
1	Coal and peat	7	0.38	7	0.37	7	0.37	5	0.30
2	Crude oil	-	-	-	-	-	-	-	-
3	Petroleum products	1152	62.37	1190	62.40	1244	66.24	1016	60.51
4	Natural gas	131	7.09	122	6.40	96	5.11	122	7.27
5	Atomic energy	-	-	-	-	-	-	-	-
6	Hydroelectricity	-	-	-	-	-	-	-	-
7	Wind, solar energy, etc.	-	-	-	-	-	-	-	-
8	Biofuels and waste	25	1.35	37	1.94	28	1.49	28	2.26
9	Electricity	313	16.95	333	17.46	316	16.83	325	19.36
10	Heat energy	218	11.80	219	11.48	188	10.01	174	10.36
11	Total	1847	100.0	1907	100.0	1878	100.0	1669	100.0

Source: formed by the authors according to the State Statistics Service of Ukraine [11]

Note. 2017–2020 without taking into account the temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol and part of the temporarily occupied territories in Donetsk and Luhansk regions.

Thus, Ukraine has a well-developed agriculture, the waste from which provides an excellent raw material base. According to the State Agency for Energy Efficiency and Energy Saving, the use of only 37% of waste from livestock and crop production will produce more than 10 billion m^3 of gas. Table 3 lists potential substrates (agricultural waste) for biogas production.

Given the above, it can be concluded that the existing potential of biogas production from organic agricultural waste in Ukraine and the significant benefits of using biogas technologies for energy generation create favorable conditions for the development of the domestic agrobiogas sector. According to the Bioenergy Association of Ukraine, the average electricity production from biogas in 2020 was about 36.0 million kWh. Capital cost savings when using biogas plants in enterprises is 30-40%.

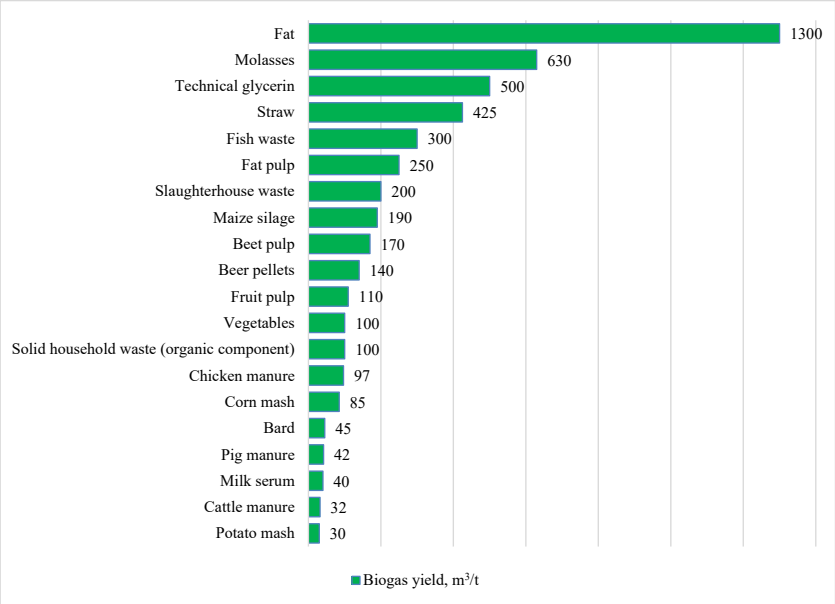

Figure 3. Biogas yield from 1 ton of substrate

Source: generalized by the authors on the basis of processed literature sources

The chemical composition of biogas produced in biogas reactors is close to natural, without its purification (natural: methane (CH4) – 80-90%, carbon dioxide – up to 10%, biogas: methane (CH4) – 65-70%, carbon dioxide – up to 30% In terms of heat of combustion 1 m³ of biogas is equivalent to: 0.8 m³ of natural gas, 0.7 kg of fuel oil, 0.6 kg of gasoline, 0.85 liters of alcohol, 1.6 kg of firewood, 1.4 kW. The total calorific value of biogas is from 5,000 to 8,000 kcal/m³. So biogas can be used as natural gas: to accumulate, pump, generate electricity, use as fuel for internal combustion engines [6].

Equating the selling price of biogas to the cost of natural gas (UAH 9.9 thousand per 1000 m³), the gross profit from biogas production for agricultural formations of Ukraine can range from 5.08 to 24.86 million UAH. depending on the type of raw material. For the company, the advantages of implementing a biogas plant are cost savings through the

Table 3

Biogas output potential from agricultural waste

Substrate	Dry matter (SR), %	Dry organic matter (COP), %	Specific yield of biogas, m^3/t COP	Specific yield of biogas, m^3/t
Crop by-products				
Corn silage	32.0	95.0	700.0	212.8
Straw	30.0	90.0	600.0	162.0
Grass silage	30.0	89.0	550.0	1416.9
Sugar beets	23.0	90.0	800.0	165.6
Mangold	12.0	75.0	620.0	55.8
Oilcake	28.0	94.0	680.0	179.0
Livestock by-products				
Pig manure	3.0	85.0	425.0	10.8
Cattle manure	25.0	80.0	350.0	70.0
Bird droppings	24.0	85.0	425.0	86.7

Source: formed by the authors on the basis of data from the Bioenergy Association of Ukraine [4]

production of electricity and heat from its own raw materials, reducing dependence on external energy sources, the ability to provide energy to other consumers. From 1 m^3 of biogas it is possible to produce about 2-2.5 kWh of electricity and up to 2.5-3 kWh of heat energy by cooling the engines after burning biogas to produce electricity. However, the economic benefits of using biogas in each case will depend on the type of waste available for processing, investment opportunities, the availability of the local energy market and government initiatives [14, p. 196].

For agricultural enterprises, the advantages of implementing environmentally friendly waste-free technologies for biogas production from waste are cost savings through the production of electricity and heat from their own raw materials, reducing dependence on external energy, the ability to provide energy to other consumers. However, the economic benefits of using biogas in each case will depend on the type of waste available for recycling, investment opportunities, the availability of a local energy market and government initiatives. For example, in European practice, farmer's biogas plants are common, usually owned by a single farmer, and centralized biogas plants, which have more capacity and are

usually cooperative property (owned by several farmers) and are considered more cost-effective. scale effect). When planning, first all available resources are identified and the possibilities of their use in different scenarios are calculated, after which a decision is made on the location, type of installation, capacity and load. In the countries of the European Union, the payback period of biogas plants for processing waste from the agro-industrial complex averages 6-14 years, or taking into account the green tariff for the sale of electricity to the grid – 4-8 years [14, p. 198].

The mechanism of biogas production from agricultural waste at agricultural enterprises to ensure energy security is presented in Figure 4.

Thus, the bioenergy model of biogas production from agricultural waste provides a significant environmental effect:

– at the local level the problem of pollution of both groundwater and water basins in general by pathogens and chemicals is solved; there is an improvement in the quality of drinking water directly near livestock farms or poultry farms; the unpleasant smell disappears near the objects of the livestock industry;

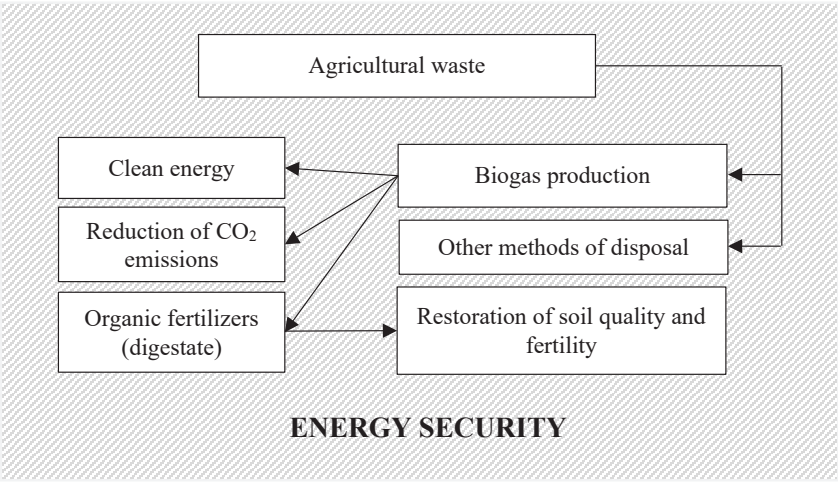

Figure 4. Bioenergy model of biogas production from agricultural waste

Source: developed by the authors

– with the use of biofertilizers obtained from the production of biogas, the problem of increasing soil fertility and preventing their degradation is solved; reduces weeds, acidity, salinity of soils; Organic organic food is obtained, which has a positive effect on the health of the population;

– at the global level, there is a reduction in greenhouse gas emissions, which contributes to the implementation of state environmental commitments.

In Vinnytsia region there are two powerful enterprises for the production of biogas from livestock waste – LLC "Vinnytsia Poultry Farm", and biogas from crop waste – LLC "Yuzefo-Mykolayiv Biogas Company". The region is not only a leader in the production of gross agricultural output, but also can become one of the leaders in the implementation of waste-free technologies that provide a full cycle of recycling economy.

Another striking example of the efficient use of recycled waste from its own production is a young agricultural enterprise in the Vinnytsia region – Organic-D LLC, which operates on the principle of waste-free production, using its own biogas plant.

The algorithm of this station is as follows – the remains of animals from the premises are merged into a biogas plant and fermented for 30 days. As a result of the biogas plant, the company receives:

– biogas output (1200 m^3/day);

– volume of electricity (250-300 kW) and heat energy (300-350 kW);

– organic fertilizer digestate (60 t/day), which enriches its own agricultural land [15, p. 518].

The introduction of biogas plants on agricultural enterprises will allow to establish an environmentally friendly, waste-free method of processing, disposal and disinfection of various organic wastes of plant and animal origin. On the other hand – such installations become a source of additional income, reduce costs and cost of production by providing energy and organic fertilizers of the main production of enterprises. When using a biogas plant, the actual energy consumption is 20% of the received. In the case of using biogas for the simultaneous production of electricity and heat (cogeneration), 30-40% of energy is converted into electricity, 40-50% – in heat, the rest is sent to their own needs.

Thus, agriculture, in particular livestock, can make an important contribution to combating climate change by moving to a circular economy,

sustainable production through the introduction of environmentally friendly resource-saving technologies for processing crop residues and animal manure into biofuels. Utilization of agricultural waste, namely livestock waste by processing it into biogas, is an important aspect not only of environmental friendliness of this process, but also contains an energy component – energy security, ie use of renewable raw materials and abandonment of fossil fuels or imports, energy diversification. However, the economic benefits of using biogas in each case will depend on the type of waste available for recycling, investment opportunities, the availability of a local energy market and government initiatives.

5. Development of waste-free biogas technologies in the world

Currently, more than 65 countries around the world use biogas plants to produce biogas as an alternative energy source. China is the leader in the use of biogas technologies, with more than 15 million biogas plants. 86% of China's alternative sources are made from agricultural waste and only 14% from industrial and sewage waste. China has a medium- and long-term plan for the development of renewable energy in order to achieve an annual level of biogas production of 50 billion m^3, which should be provided by both industrial-type biogas plants and low-power home stations. In India, there are about 10 million biogas plants [16, p. 806].

As of the end of 2019, there were 18,838 biogas plants in operation in Europe (this figure increased by 4% compared to 2018 and by 69% compared to 2009) (Figure 5). Currently, the EU biogas sector produces 15.8 billion cubic meters of biogas and 2.43 billion cubic meters of biomethane, with 75% of biogas produced from agricultural waste, 17% from organic waste from private households and businesses and another 8% from sewage treatment plants [17].

Today, the leader in biogas production in Europe is Germany, where there are about 11,000 biogas plants (about half of all global plants), but only 7% of biogas produced by enterprises goes to gas pipelines, the rest is used for the needs of producers. Germany produces 93% of biogas through fermentation of crops and crop residues. In the future, with the optimal use of biogas in Germany, electricity from this type of fuel will be able to provide 12 million households. Already, electricity and heat produced from biogas are enough for about 500,000 private homes and apartments.

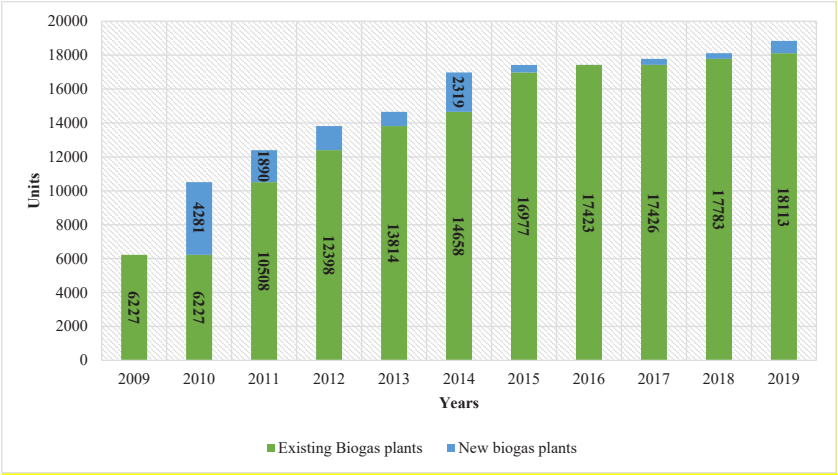

Figure 5. Dynamics of increasing the number of biogas plants in Europe, 2009–2019

Source: based on data from the European Biogas Association [18]

As the German Federal Law on Renewable Energy creates favorable conditions for the use of biomass, it is natural that three of the six largest European companies in the biogas industry are German: Strabag Umweltanlagen GmbH, Schmack Biogas AG, Biotechnische Abfallverwertung – with a total of 280 plants and 280 production of about 3.7 million tons [14, p. 194–195].

According to the European Biogas Association, the leaders in the number of biogas plants, in addition to Germany, are Italy – 1491, Great Britain – 813, France – 736, Switzerland – 633, Czech Republic – 554, Austria – 436 plants [18].

Among the European countries with a high rate of development of biogas technologies that work on agricultural waste can be identified, as already mentioned, Germany, as well as Italy, France and the Czech Republic; for solid waste – Great Britain, Spain, Italy and France; from wastewater effluents – Sweden, Lithuania, Poland [19, p. 106–107].

In the United States, despite the large number of farms, the biogas market is developing at a much slower pace than the European one. There are about

2,100 biogas plants in the country, which mainly operate on agricultural waste, including livestock waste (cattle manure). The total capacity of all plants on such farms is approaching 60 MW. The US biogas plant market is estimated at $ 2.4 billion in 2020. Most American biogas plants are concentrated in New York, Pennsylvania, Vermont and Wisconsin. However, they cover only a small part of the 8,000 farms where biogas production could be introduced. Thus, according to American experts, on average, a herd of 1,000 cows can provide fuel for about 250 kW of generating capacity, so the potential of all US farms to generate energy from biogas reaches 1,600 MW [20].

According to experts from the European Biogas Association, the next ten years will see rapid growth in the biogas and biomethane sectors, and in the future the share of biomethane in European gas production will be 33-40%. At the same time, members of the European Biogas Association believe that the potential for biogas and biomethane production in Ukraine is quite high. Not surprisingly, in 2019 Ukraine ranked 8th among the 100 developing

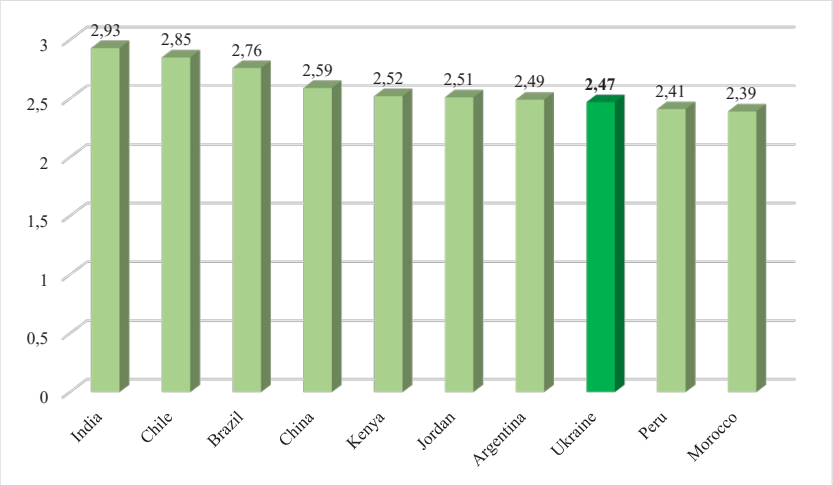

Figure 6. Estimation of attractiveness of investments in renewable energy sources among developing countries in 2019

Source: based on the annual Climatescope report [21]

countries in terms of attractiveness of investment in renewable energy sources (RES) [10], which is 55 places higher than in 2018 (Figure 6).

Investing in biogas plants for large agricultural enterprises solves several problems. One of the most important is the processing of waste, which is especially relevant for livestock complexes. The cost of burying manure that pollutes the environment and harms the environment is in the hundreds of thousands. It is wiser to spend this money on the construction of a biogas plant. The resulting biogas will be used as fuel for the heating system, or will be used for other purposes.

The task of introducing waste-free technologies in agro-industrial production is extremely important in today's conditions and is to create closed production cycles with recycling of raw materials, when each end of one production serves as a starting point of the next, resulting in no waste and minimizes negative consequences. natural environment. That is why it is so important to intensify research and innovative developments to create new waste-free technologies for agricultural production.

The high initial cost of investment and a fairly long payback period (4-8 years) of biogas plants contribute to the reduction of the number of actual and potential investors in RES. One of the solutions to this problem is the creation of an energy cooperative – a voluntary association of individuals and / or legal entities on a share basis to conduct joint economic activities in the field of energy efficiency or RES [22].

Germany and Austria are among the leading countries in the establishment of energy cooperatives. For example, in Germany in 2019, 14 energy cooperatives were established. These include six local heating cooperatives and two energy cooperatives, each specializing in photovoltaics and wind energy. The business models of other new energy cooperatives are very different.

According to the Federal Office for Energy Cooperatives, there are a total of 843 energy cooperatives in Germany by the end of 2020, bringing together 200,000 people. They invested a total of 2.9 billion euros in renewable energy and generated about 8.31 TWh of clean electricity in 2019. This avoided 3.39 million tons of CO_2 emissions [23].

Another example of the creation of energy cooperatives is the United Kingdom. Currently, there are a large number of energy cooperatives in this country that specialize in renewable energy sources. There are cooperatives that produce and use solar, wind, hydro and biomass energy.

In the United States, quite a large part of the electricity market is occupied by energy cooperatives, which are formed by communities. In total, there are 903 cooperatives in this country that deal with the distribution (delivery to the final consumer) of electricity. They provide power to 42 million people in 47 states. The service areas of these cooperatives cover 75% of the United States. All these networks, together with all the equipment belonging to them, are in the direct ownership of the members of the respective energy cooperatives [24].

6. Ecologization of soils through the introduction of waste-free technologies of agriculture

Plowing of agricultural land in Ukraine is one of the highest in the world and reaches 78.1%. In 2019–2020, the plowing of agricultural land in some regions of Ukraine reached 80-90% (Vinnytsia – 85.7%, Donetsk – 81.0%, Zaporozhye – 84.8%, Kirovograd – 86.8%, Lugansk – 66.4%, Mykolaiv – 84.5%, Odessa – 79.7%, Ternopil – 81.4%, Kherson – 90.2%, Cherkasy – 87.6%). While the amount of plowed agricultural land in the United States is 38.9%, China – 21.5%, Great Britain – 35.3%, Austria – 47.5%, in the Netherlands the percentage of plowing is 55%. At the same time, in these countries the level of GDP is much higher and the share of agro-industrial complex in GDP is from 1 to 3%, while in Ukraine – more than 12%. This indicates that Ukraine is gradually transforming from an industrial-agrarian country to an agrarian country with clear characteristics of the raw material type [1, p. 230].

The structure of agricultural land in Ukraine in 2020 is shown in Figure 7.

Intensive agricultural land use affects the reduction of soil fertility, as noted by Honcharuk I. [26, p. 27], in connection with their compaction, destruction of structure, permeability and aeration capacity with all environmental consequences. Land degradation and desertification are one of the most serious challenges to the country's sustainable development, causing significant environmental and socio-economic problems.

Due to land degradation during 1986–2020, the humus content decreased by 0.19% and is 3.17%. During this period, the loss of humus in the arable layer was 5500 kg/ha. Every year, with the harvest of agricultural crops, 77-135 kg of nutrients (nitrogen, phosphorus, potassium) are irrevocably alienated from each hectare. To ensure a deficit-free balance of humus in soils and their deoxidation, the urgent task is to change the fertilizer

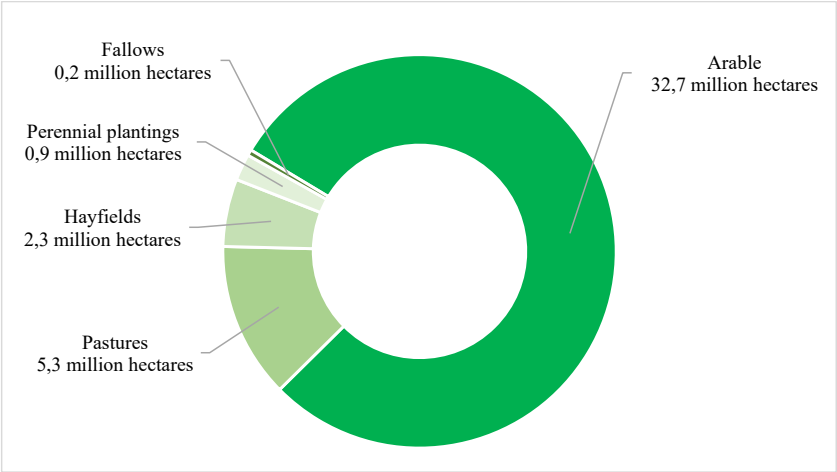

Figure 7. The structure of agricultural land in Ukraine in 2020

Source: formed by the authors on the basis of the Land Directory of Ukraine-2020 [25]

application system with a reorientation to increase the share of organic fertilizers. The amount of organic fertilizers per 1 hectare in 2020 compared to 1990 decreased by 22 times. Decrease in livestock relative to 1990 levels: cattle – 7.5 times, pigs – 3.3 times, goats and sheep – 7 times (Table 4).

To ensure a deficit-free balance of humus in soils and their deoxidation, the urgent task is to change the mineralization system with a reorientation to increase the share of organic fertilizers. One of the ways to solve the problem of soil degradation in Ukraine is to use as an organic fertilizer digestate – a by-product of processing organic matter that remains after biogas production. During the separation of the digestate, solid (sludge) and liquid (concentrate) fractions are formed.

Digestate is liquid and solid. Liquid digestate is added to the soil, and the solid fraction of digestate can be dried, granulated and conveniently combined with other wastes. It is also convenient to combine with other wastes or organic products, such as wood chips, sawdust. Digestate improves the condition of crops by providing additional nutrients and helping to maintain the necessary soil moisture. If mineral fertilizers are absorbed only by 35-50%, then biofertilizers – almost 99% [26, p. 27].

Table 4

The state of maintaining the content of organic matter (humus) in the soils of Ukraine in 1990–2020

Indicator	Years						Deviation 2020/1990, +/-
	1990	2016	2017	2018	2019	2020	
Livestock of cows, million heads	25.2	3.9	3.8	3.7	3.5	3.3	-21.9
Livestock of pigs, million heads	19.9	7.4	7.1	6.7	6.1	6.0	-13.9
Livestock sheep and goats, million heads	9.0	1.4	1.3	1.3	1.3	1.3	-7.7
Poultry, million heads	255.1	213.3	204.0	201.7	204.8	211.7	-43.4
Volume of applied organic fertilizers, million tons	260.7	9.7	9.2	9.3	11.6	11.4	-249.3
Application of organic fertilizers per unit area of agricultural land, kg/ha	6207.8	232.8	220.8	223.5	280.7	274.3	-5933.5
Areas treated with organic fertilizers, million hectares	5.5	0.4	0.5	0.5	0.8	0.8	-4.7
The total amount of mineral fertilizers applied, million tons N, P_2O_5 i K_2O	4.4	1.4	1.7	2.0	2.3	2.3	-2.1
The amount of mineral fertilizers per unit area of agricultural land, kg N, P_2O_5 i K_2O /га	105.1	34.1	41.7	48.9	56.5	56.3	-48.8
Areas treated with mineral fertilizers, million hectares	26.4	14.5	15.7	16.5	16.1	16.4	-10.0
Humus content in the soil, %	3.36	3.17	-	-	-	-	-

Source: calculated according to the State Statistics Service of Ukraine and the Institute of Soil Science and Agrochemistry

Currently, the total formation of digestate at biogas plants in Ukraine is about 2 million tons and will increase with the number of biogas capacity in Ukraine. Thus, 780 kg of digestate is formed from 1 ton of corn silage, 890 kg from 1 ton of chicken manure, 910 kg from 1 ton of pulp, 920 kg from cattle manure, and 990 kg from pig manure. For every megawatt of biogas plant capacity, 40-50 thousand tons of such digestate are formed per year.

The first experiments with the use of digestate as a fertilizer showed that it has an effect and this effect is even higher than that of more traditional counterparts. For example, in England, digestate (although from food waste) has increased winter grain yields by 10% on average over 3 years, while green compost – by 7%, mixed compost (from green mass and food waste) – by 8%, manure – by 9% and manure with straw – by 10%. In another experiment, the application of 30 m^3/ha of digestate, each ton of which contained 3.6 kg of nitrogen, 1.7 kg of P_2O_5 and 4.4 kg of K_2O, saved 108.6 euros/ha of mineral fertilizers [27].

"Myronivsky Khliboprodukt", the company that owns powerful biogas plants in Dnipropetrovsk and Vinnytsia regions, was the first in Ukraine to use digestate from biogas plants as an organic fertilizer. The main raw material of biogas plants is chicken manure. In the Dnipropetrovsk region, small amounts of sorghum silage are added to it, in Ladyzhyn – straw and cattle manure.

The digestate obtained at "Myronivsky Khliboprodukt" biogas plants had the following composition:

Liquid fraction: pH – 7.7-9.1. In 1 m^3 of total: nitrogen – 6.6 kg, phosphorus – 1.9 kg, potassium – 6.2 kg. Manganese – 21 mg/kg, zinc – 8.2 mg/kg, copper – 14.1 mg/kg, cobalt – 7.2 mg/kg, sulfur in the liquid – 0.27%.

Solid fraction: pH – 7.7-9.3. General: nitrogen – 6.8 kg/t, phosphorus – 3.1 kg/t, potassium – 2.7 kg/t. Manganese – 47.65 mg/kg, zinc – 12.5 mg/kg, copper – 34.5 mg/kg, cobalt – 18.1 mg/kg, sulfur in the liquid – 1.56%.

In Vinnytsia region, the experiment was set up in the fields of winter wheat by a farmer in the village of Vasylivka near Ladyzhyn, not far from the biogas plant. The soil in this area was acidic and low humus (only 1.5%). Two variants of digestate application were tested – in August (barrels for liquid fertilizers) and in March (via hose-drum irrigation machines). In the first section in February, the wheat was thicker and generally better than

in the control. On the second, after some time, it was also noticeable that wheat is greener than in neighboring areas, where the traditional scheme of feeding mineral fertilizers was used [27].

Despite the positive developments, the use of digestate as an organic fertilizer to increase soil fertility is currently not widespread. The main barriers to the use of digestate biogas plants as organic fertilizers in Ukraine are the following:

1. Most biogas projects in Ukraine are based on the concept of an energy company focused on obtaining basic income from the sale of electricity at a "green" tariff – the placement of digestate on the market as an organic fertilizer was not considered.

2. Most biogas plants in Ukraine do not regularly control the quality of raw materials and digestate according to a set of indicators, and technological regimes change throughout the year – the physico-chemical composition of digestate is uncontrolled and unpredictable.

3. Digestate from most biogas plants in Ukraine cannot be considered an organic fertilizer for organic crop production – lack of demand in the segment of the organic production market.

4. Lack of state control over the quality of digestate and its management, as well as the lack of its own system to ensure / standardize the quality of digestate generated by operators of most biogas plants in Ukraine – lack of trust among potential consumers and, consequently, demand.

5. Lack of a system of voluntary certification and quality assurance of digestate (outside the market segment of organic production) – lack of opportunity to create an image of a quality product – lack of trust among potential consumers and, accordingly, demand.

6. The lack of state norms and requirements for the production and use of organic fertilizers in general, and digestate in particular – slows down the creation of a market for organic fertilizers from digestate.

Thus, the digestate of biogas plants can be a valuable resource for maintaining / restoring soil fertility in Ukraine and make a significant contribution to the substitution of imported mineral fertilizers. When using the digestate, it was found that it is universal and suitable for all soils, as well as for feeding all types of plants; increases the content of organic matter (humus); improves water and air regime of soils; it can be made at any time; has neutral acidity and deoxidizes the soil; absence of pathogenic

organisms; allows you to increase yields, as it contains a full range of essential macro-and micronutrients, organic compounds that improve soil structure and humic acids; creates preconditions for the development of organic agricultural production and increase income from sales.

7. Conclusions

Thus, the need for ecologization of agriculture is due to the sharp deterioration of the ecological resources of natural resources associated with agricultural production, reducing soil fertility and quality of agricultural products, significant accumulation of agricultural waste, increasing complex ecological and destructive impact on the environment.

Based on the research, it was determined that an important aspect of ecologization agricultural production is the use of waste-free technologies in enterprises. The problem of waste in the agricultural sector of Ukraine requires the development of a new vision: waste from the agricultural sector should be considered as a source of secondary material and energy resources; it is necessary to minimize the generation of waste from the agricultural sector in the process of production and consumption by efficient methods; it is necessary to ensure maximum processing and utilization of waste from the agricultural sector, implementing the most efficient waste management technologies (waste-free technologies); at each stage of waste generation it is necessary to determine the methods of reuse of natural resources (recycling) and recycling of waste; Waste management of the agricultural sector should begin with planning the rational use of natural resources and production of agricultural products as raw materials for industrial processing, and continue with the design of the entire life cycle of production and consumption of various useful products.

The introduction of waste-free agricultural production into modern economic activity involves the balanced use of nutrients, energy and nature, while ensuring resource efficiency, competitiveness, innovation, increasing employment and welfare and income from agricultural production.

We believe that one of the most promising areas of implementation of waste-free technologies in agricultural enterprises is the processing of crop and livestock waste into biogas – the only type of RES that can be used in several ways. It can be burned in heating installations and receive heat for heating. The introduction of biogas plants on agricultural enterprises

will allow to establish an environmentally friendly, waste-free method of processing, disposal and disinfection of various organic wastes of plant and animal origin. On the other hand – such installations become a source of additional income, reduce costs and cost of production by providing energy and organic fertilizers of the main production of enterprises.

The ecological effect of biogas production is the safe processing of organic waste and by-products of animal origin, due to methane fermentation. In total, we have identified 5 main environmental effects from the introduction of biogas complexes in agricultural enterprises:

1) use of crop and livestock waste as secondary raw materials to ensure energy autonomy;

2) solving the problem of storage and transportation of raw materials;

3) reducing the use of fossil fuels, resource conservation and the introduction of alternative energy sources;

4) use of digestate as an organic fertilizer to increase soil fertility;

5) reduction of greenhouse gas emissions.

As indirect environmental effects can be identified – to prevent contamination of groundwater and surface water and soil.

Ukraine has great raw material potential for biogas production and significant opportunities to increase the capacity of biogas plants. Processing of organic waste from production and consumption in a biogas plant is an economically and environmentally optimal solution. The products (biogas, biofertilizers) generated as a result of waste disposal help to solve the problem of meeting the needs of certain categories of material resources, namely energy and fertilizers, which will increase production while reducing the use of natural resources. Replacement of energy and fertilizers with biological analogues, which is achieved through the disposal of industrial waste for biogas, as well as a significant reduction in their imports – have a positive impact on the internal balance in the country and its GDP.

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