CHAPTER «AGRICULTURAL SCIENCES»

WASTE-FREE TECHNOLOGYS FOR THE PRODUCTION OF BIOFUELS FROM AGRICULTURAL WASTE AS A COMPONENT OF ENERGY SECURITY OF ENTERPRISES

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Abstract. The purpose of the study is to substantiate the economic efficiency of the use of waste-free technologies in the agro-industrial complex to achieve the energy and environmental safety of the branch. The theoretical and methodological basis of the study was formed by the results of fundamental national and foreign research on the problems of agro-industrial production. The subject of scientific work is the theoretical, methodological and practical foundations of the current state of development of waste-free technologies in Ukraine. The research was based on the following methods: a systematic approach – for study the links between phenomena and processes of subjects of waste-free agro-industrial production; dialectical – for consider phenomena in their relationship and development, in particular when considering the processes of combination, specialization, concentration, cooperation in the organization of waste-free agro-industrial production; theoretical generalization and comparison – for the development of the conceptual apparatus; various techniques of the economic and statistical method (statistical observation, comparison, tabular, graphical) – for the development of a visual illustration of the phenomena under study; abstract-logical – to summarize research results and formulate research conclusions.

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The monograph substantiates the relevance and potential of introducing waste-free production technologies, the introduction of which will significantly reduce the cost of production and increase the profitability indicator, stimulate the development of autonomous entrepreneurship, and improve the state of the country's environmental and energy security. The dynamics of the volume of generated and utilized agricultural waste in Ukraine in 2017–2020 has been analyzed and it was determined that no more than 30% of waste is disposed of, the share of which has been rapidly decreasing in recent years. It has been substantiated that the most promising direction for introducing waste-free technologies at agricultural enterprises is the production of biogas from organic waste (agrobiomass). It is noted that agricultural waste, mainly animal waste, such as manure, chicken droppings, can be an additional source of replenishing the energy balance of agricultural enterprises and ensuring the energy security of the region.

Recycling organic waste from production and consumption in a biogas plant is an economically and environmentally optimal solution. At the same time, the products formed as a result of waste disposal (biogas, digestat) help to solve the problem of meeting the need for certain categories of material resources, namely energy and fertilizers, which will increase production volumes, provided that the use of natural resources decreases.

The study is based on the main tasks of the research work of young scientists "Development of a new concept for the use of agricultural waste to ensure the energy autonomy of agricultural enterprises", state registration number 0119U100786.

1. Introduction

The problem of waste management in Ukraine is of particular scale and significance due to the dominance of resource-intensive multi-waste technologies in the national economy, and the absence for a long time of an adequate response to violations of the norms of waste generation. The large scale of resource use and the energy and raw materials specialization of the national economy together with an outdated technological base is the reason for the high rates of waste generation. The success of waste use is directly dependent on the level of development of productive forces, the organization of production and the nature of social relations in the sectors of the national economy. Despite certain positive shifts in the process of processing waste

as secondary raw materials, over the past decade, this problem has not lost its priority. Almost all anthropogenic pressures on nature can be reduced to the problem of waste. They will always be – absolutely waste-free production is impossible. The way out of this situation is that the quantity and quality of waste should be such that it can be fully recycled, assimilated without damage to wildlife, that is, there is an urgent need to introduce ecological non-waste technologies at agricultural enterprises.

The need for a transition to new non-waste technologies was caused by the understanding that the overwhelming majority of existing production technologies are open systems in which natural resources are irrationally used and significant volumes of waste are generated, which are sources of environmental pollution. Modern society is too wasteful of natural resources, producing more and more short-lived consumer goods with inefficient technologies, resulting in an enormous amount of waste.

The agro-industrial complex is one of the material-intensive and rich-and-liquid sectors of the economy, and is also a significant source of greenhouse gas emissions due to the use of fossil fuels, the burning of plant residues in the fields, non-compliance with the norms for the disposal of crop and livestock products, food waste, land use principles, and the like. According to the National Inventory of Greenhouse Gas Emissions the share of agriculture in total emissions in 2018 in Ukraine was 12.9% [1].

Waste-free agricultural production is the main task of future technological developments that will allow humanity to develop sustainable and reduce the anthropogenic impact on the environment. Waste recycling is a promising method for obtaining additional material resources, reducing production costs, saving money on waste disposal.

Ukraine has untapped potential for the production of its own energy from renewable sources through the processing of animal waste (animal manure and poultry droppings) with the formation of biogas. Biogas obtained from biomass is used as a fuel, harmless to the environment, since it does not cause additional emissions of the greenhouse gas CO_2 and reduces the amount of organic waste. Unlike wind and solar energy, biogas can be produced regardless of climatic and weather conditions [2, p. 32].

The transition to waste-free agricultural production is an objective process, closely related to the depletion of reserves of natural raw materials and energy carriers. In modern conditions, much attention is paid to the

search for rational ways of waste disposal, however, insufficient, in our opinion, is the study of the general aspects of the introduction of waste-free technologies in agricultural production. Accelerated developments in this direction and the use of their results in economic practice are becoming an urgent requirement today.

2. Analysis of recent research and publications

The idea of developing waste-free technologies appeared in the last century and still does not lose its relevance. These questions have found their theoretical reflection in the works of such economists as A. Andreichenko, O. Bondar, I. Honcharuk, G. Geletukha, T. Emchik (Honcharuk), G. Kaletnik, I. Kirilenko, N. Prishlyak, D. Tokarchuk, O. Khodakivska, A. Shpikulyak, A. Shpichak and others.

I. Honcharuk in her writings studied in detail the structure of emissions from the agro-industrial complex of Ukraine, where she noted that animal husbandry leads to 18% of greenhouse gas emissions, in particular, methane emissions from this industry account for about 16% of the annual global emissions, nitrogen oxide – 17% and many other dangerous for the environment of substances and compounds (Figure 1) [3, p. 10–11].

In addition, I. Honcharuk devotes his works to the study of the use of animal waste to ensure energy independence and replenishment of the energy balance, the author also substantiates the relevance and potential for the introduction of waste-free production technologies, which entails a number of advantages for the enterprises and the country as a whole [3]; G. Kaletnik, I. Goncharuk and Yu. Okhota pays attention to the need to develop waste-free production for the formation of energy autonomy of agricultural enterprises in Ukraine [4]; T. Emchik (Goncharuk) in his works analyzes the basic principles of using renewable and alternative energy sources as an important factor in increasing energy security and reducing anthropogenic impact on the environment [5]; I. Kirilenko and D. Tokarchuk focus on methods of utilization of agricultural waste, in particular, animal waste, and substantiate that modern methods of utilization of animal waste in the production of biogas have significant environmental and economic advantages [6]; A. Andreichenko explores the concept of waste-free technologies in the framework of achieving maximum efficiency of public production and ensuring energy security [7].

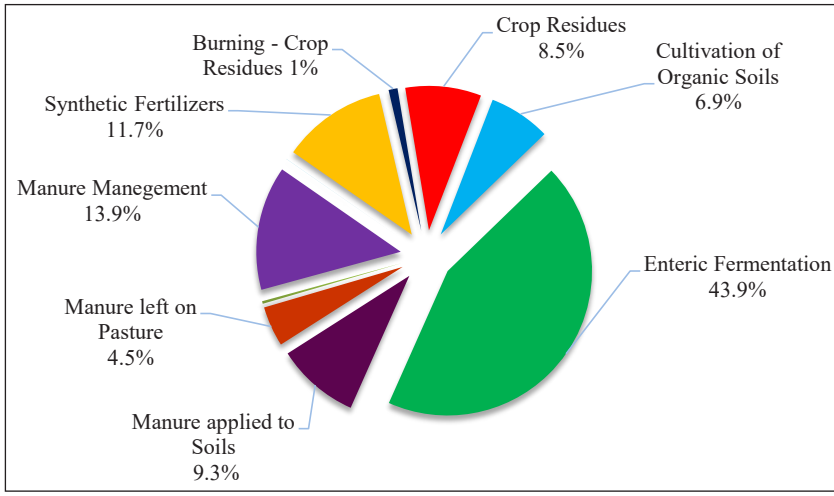

Figure 1. Structure of AIC Ukraine emissions, average 1990–2017, CO_2 equivalent

Source: [3, p. 11]

A large number of studies are devoted to the technological implementation of individual ideas of the recycling economy, the introduction of "green" innovations and waste recycling in production, as well as the economic aspects of their practical implementation in various fields. Giving due due to the scientific heritage of scientists, it should be noted that it is insufficient to study the issue of introducing waste-free technologies in the agricultural sector.

3. Purpose and methods of research

The study of the features of the safe disposal of agricultural waste and the search for effective methods of their use as a secondary raw material to ensure the energy autonomy of the enterprises themselves and the country as a whole are carried out as part of the research work of young scientists of Vinnitsa National Agrarian University "Development of a new concept for the use of agricultural waste to ensure energy autonomy of agricultural enterprises".

The purpose of the study is to substantiate the economic efficiency of the use of waste-free technologies in the agro-industrial complex to achieve the energy and environmental safety of the branch.

The theoretical and methodological basis of the study was formed by the results of fundamental national and foreign research on the problems of agro-industrial production. The subject of scientific work is the theoretical, methodological and practical foundations of the current state of development of waste-free technologies in Ukraine. The research was based on the following methods: a systematic approach – for study the links between phenomena and processes of subjects of waste-free agro-industrial production; dialectical – for consider phenomena in their relationship and development, in particular when considering the processes of combination, specialization, concentration, cooperation in the organization of waste-free agro-industrial production; theoretical generalization and comparison – for the development of the conceptual apparatus; various techniques of the economic and statistical method (statistical observation, comparison, tabular, graphical) – for the development of a visual illustration of the phenomena under study; abstract-logical – to summarize research results and formulate research conclusions.

4. Environmental problems of recycling and utilization agricultural waste

Agriculture in Ukraine in terms of its scale, production volume, export orientation, is a priority sector of the economy. The products of agricultural enterprises are the key to food security and independence of the country. However, despite the achievements in the field of agriculture (increasing the productivity of agricultural crops, animal productivity, etc.), there are many problematic issues that require urgent solutions. One of these, undoubtedly, is the utilization of wastes from the activities of enterprises in the agricultural sector, especially animal husbandry. This problem is acquiring a national character, as farmers concentrate their activities in all regions of the country without exception. One of these, undoubtedly, is the utilization of wastes from the activities of enterprises in the agricultural sector, especially animal husbandry. This problem is acquiring a national character, as farmers concentrate their activities in all regions of the country without exception.

Agricultural enterprises do not even plan indicators that characterize their work on improving soil fertility, applying especially organic fertilizers. Therefore, millions of tons of organic fertilizers are accumulated on farms. Wastewater from livestock breeding complexes is a double hazard, as it

causes both chemical and biological pollution (microorganisms). Moreover, they pollute both the soil directly and water and air. From one pig farm for 10-40 thousand animals per hour, up to 605 kg of dust, 14.4 kg of ammonia, 83.4 billion worth microorganisms enter the air.

A typical one hundred thousandth pig farm produces about 1000 m^3/day (up to 365,000 m^3/year) of purulent effluent. For the safe introduction of such a quantity of wastewater from the lagoons, up to 10 thousand hectares of land are needed [8].

Often, if improperly stored, liquid manure enters the beams and pollutes the groundwater. For example, a pig farm for 100 thousand heads. or a complex of cattle for 35 thousand heads. can give pollution, equal to environmental pollution from a large industrial center with a population of 400-500 thousand people.

In Figure 2 shows the amount of generated and utilized agricultural waste during 2017–2020.

Analyzing statistical data, one can see that waste generation significantly exceeds disposal. It is obvious that in Ukraine there is a small percentage of

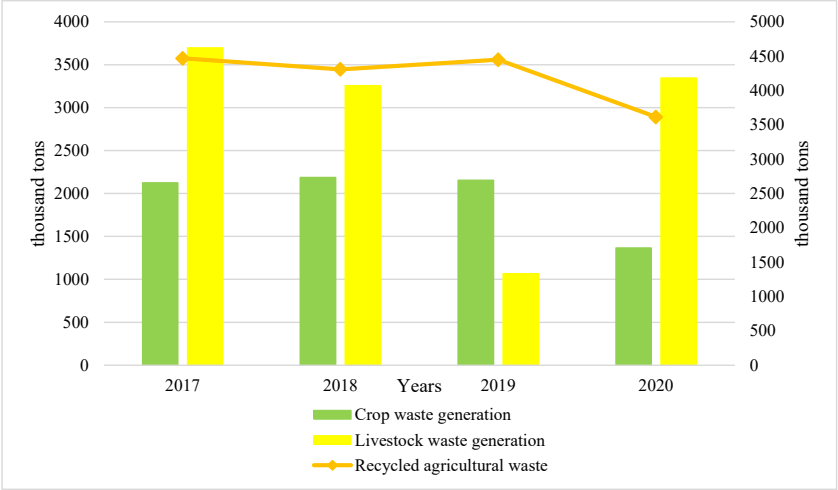

Figure 2. Volumes of education and utilization of agricultural waste (crop and livestock) in 2017–2020, thousands tons [9]

Source: [9]

the use of environmentally friendly technologies for waste utilization and there is not enough capacity for their processing. An increase in livestock production leads to the emergence of negative trends – the formation and accumulation of large volumes of manure, poultry droppings and the impossibility of utilizing it as organic fertilizer, since uncontaminated manure is a source of environmental pollution, water and air basins. The decay products of animal waste are such harmful emissions as methane, carbon dioxide, hydrogen, hydrogen sulfide, and ammonia. The damage to the ecosystem from such emissions at livestock complexes can reach tens of millions of hryvnias. In many countries, there are national and regional programs to reduce the negative pressure of these wastes on the environment.

Accordingly, the main problems that accompany the intensive development of the livestock industry are:

– pollution by biological and chemical compounds of the water basin (rivers, lakes, ponds, reservoirs), air and adjacent to livestock farms (poultry complexes) lands;

– lack of incentives to purchase and install equipment for decontamination, processing and utilization of waste;

– the high cost of utilizing livestock waste reduces the profitability of production;

– lack of proper state control over the removal of waste to places that are not intended for storage.

The transition to low-waste or non-waste technologies in animal husbandry can help solve the problems associated with their utilization. The main idea of waste-free production is the transformation of all raw materials received by the enterprise, its residues, as well as waste obtained in the production process, into finished products that can generate income.

The process of waste-free production is cyclical, that is, the production waste of one product is the raw material for creating the next one. This process will continue until the waste is completely eliminated. The maximum use of raw materials components indicates an integrated approach to this production. This will reduce the number of cycles in the production process, which will allow more efficient loading of equipment and reduce downtime, which will increase the number of products produced. The rational organization of the production process is the general

principle of using waste-free technologies. The organization should ensure the optimal use of resources and the search for modern environmentally friendly technologies that ensure the minimum impact on the environment. A diagram of a waste-free technological system in which waste is used as a secondary raw material is shown in Figure 3 [10, p. 380–381].

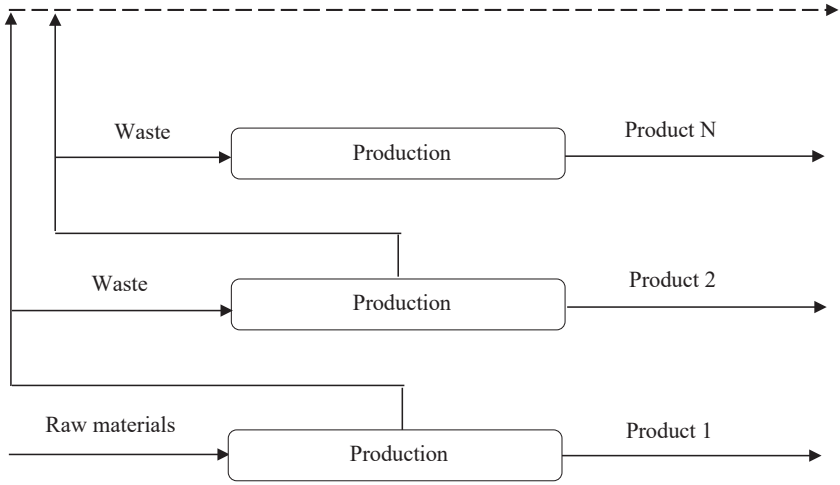

Figure 3. Diagram of a waste-free technological system in agriculture
Source: [11, p. 191]

Biomass energy is most efficiently used in Portugal, France, Germany, Denmark, Italy and Spain. Sweden and Austria provide 15% of their primary energy needs from biomass. In the United States, 4% of energy comes from biomass (almost the same as from nuclear power plants). Today biomass is the fourth most important fuel in the world, providing about 2 billion tons of standard fuel per year, which is about 14% of the global consumption of primary energy resources (in developed countries – more than 30%, and sometimes 50-80%). Bioenergy methods of waste utilization are used quite intensively in foreign countries. Such methods solve several problems at once: collection and processing of animal waste with the neutralization of harmful gases, the production of environmentally friendly fertilizers, as well as methane for mini-TPP.

A promising area of waste-free technologies today, in our opinion, is the production of biogas from agricultural waste. Considering that the amount of organic waste is growing rapidly, biogas production solves the problem of waste disposal, thereby preventing methane emissions into the environment, reducing the use of chemical fertilizers and preventing groundwater pollution.

The task of introducing waste-free technologies in agro-industrial production is extremely urgent in today's conditions and consists in creating closed production cycles with recycling of raw materials, when each end link of one production serves as an initial link in the next, as a result of which no waste enters the external environment and the negative consequences for natural environment. Therefore, it is so important to intensify research and innovative development to create new waste-free technologies for the production of agro-industrial complex.

5. Environmental and economic efficiency of biogas production from agricultural waste to ensure energy security

The large scale of resource use and energy and raw materials specialization of the national economy, together with an outdated technological base, is the cause of high rates of waste generation and accumulation. The success of waste use is directly dependent on the level of development of productive forces, the organization of production and the nature of social relations in the sectors of the national economy. Despite certain positive shifts in the process of processing waste as secondary raw materials, over the past decade, this problem has not lost its priority. Almost all anthropogenic pressures on nature can be reduced to the problem of waste. They will always be – absolutely waste-free production is impossible. The way out of this situation is that the quantity and quality of waste should be such that they can be fully recycled, assimilated without damage to wildlife, that is, there is an urgent need to introduce ecological waste-free technologies at agricultural enterprises.

The need for a transition to new waste-free technologies was caused by the understanding that the overwhelming majority of existing production technologies are open systems in which natural resources are irrationally used and significant volumes of waste are generated, which are sources of environmental pollution. Modern society is too wasteful of natural

resources, producing more and more short-lived consumer goods with inefficient technologies, resulting in an enormous amount of waste.

Biogas is predominantly a mixture of methane and carbon dioxide. Biogas formation is a biological process that takes place in the absence of air, during which organic matter is converted into methane and carbon dioxide. As a result of the implementation of this process, excellent organic fertilizer and humus are obtained. With a sufficient organization of the process from 1 kg of solid dry matter, you can get 0.3-0.45 m^3 of biogas (60% methane).

The introduction of biogas stations at agricultural enterprises will make it possible to establish an environmentally friendly, waste-free way of processing, utilizing and disinfecting various organic waste of plant and animal origin. On the other hand, such installations become a source of additional income, reduction of costs and production costs due to the provision of energy resources and organic fertilizers to the main production of enterprises. When using a biogas plant, its own energy consumption is 20% of the received one. When biogas is used for the simultaneous production of electrical and thermal energy (cogeneration), 30-40% of the energy is converted into electrical energy, 40-50% – into heat, the other part is directed to own needs.

It is well known that the biogas yield depends on the composition of the substrate, its bioavailability and production technology. It is worth considering the potential for biogas release from each individual substrate, namely, how much biogas can be obtained with an almost endless fermentation of the substrate under stable conditions. Of course, in real conditions, this figure is very rarely achieved (or almost never) due to the economic inexpediency of such a long process, but the indicator at the level of 60-95% is achievable and economically justified.

Ukraine has a well-developed agriculture, waste products of which provide an excellent source of raw materials. According to the State Agency for Energy Efficiency and Energy Saving, the use of only 37% of waste from livestock and crop farms will provide more than 10 billion m^3 of gas. Table 1 provides a list of potential substrates (agricultural waste) for biogas production.

Considering the above, it can be concluded that the existing potential for biogas production from organic agricultural waste in Ukraine and the

Table 1

Biogas yield potential from agricultural waste

Substrate	Solids (SM), %	Organic Solids (OS), %	Specific Biogas Yield, m^3/ton OS	Specific Biogas Yield, m^3/ton
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
fodder beets	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: generated by the authors

significant advantages of using biogas technologies for energy generation create favorable prerequisites for the development of the domestic sector of agrobiogas. According to the Bioenergy Association of Ukraine, the average electricity production from biogas in 2020 was about 36.0 million kWh. Saving capital costs when using biogas plants at enterprises is 30-40%.

The generally accepted practice of storing production waste (manure) in open piles or lagoons leads to environmental degradation in nearby areas. Utilization of manure in large volumes is expensive, and sanitary fines 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 the stable uninterrupted operation of the biogas plant, it is better to provide for the possibility of producing biogas from mixed raw materials – crop and livestock waste. Thus, a biogas plant operating on agricultural waste will be uniformly loaded throughout the whole year, and biogas production will become a controllable and predictable process.

According to the National Commission for State Regulation in the Spheres of Energy and Utilities [12], Ukraine's potential in replacing natural gas with biomethane and biogas produced from agricultural waste

and energoslin is about 37 billion m^3 (consumption is about 28 billion m^3) (Figure 4).

Equating the realizable value of biogas to the cost of natural gas (9.9 thousand UAH per 1000 m^3), the gross profit from biogas production for agricultural enterprises of Ukraine can reach from 5.08 to 24.86 millions UAH depending on the type of raw material. For enterprises, the advantages of introducing a biogas plant are cost savings for the production of electricity and heat from their own raw materials, reduced dependence on external energy carriers, the ability to provide energy to other consumers. With 1 m^3 of biogas, it is possible to generate about 2-2.5 kWh of electricity and up to 2.5-3.0 kWh of thermal energy by cooling the engines after burning biogas to generate electricity. However, the economic benefits from the use of biogas in each specific case will depend on the type of waste available for processing, investment opportunities, the presence of a local energy market and government initiatives [11, p. 196].

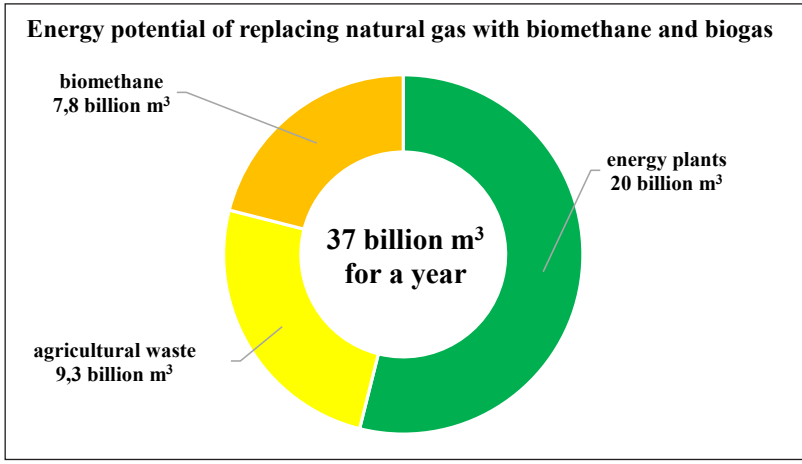

Figure 4. Energy potential of replacing natural gas with biogas from agrobiomass in Ukraine

Source: generated by the author according to [12]

The product obtained at the exit from the biogas station contains 50-70% methane. To use it in fuel transport systems or transfer to gas transmission

systems, it is necessary to carry out the so-called modernization, or the most complete purification from impurities. First of all, they include hydrogen sulfide and carbon dioxide. The methane content must be brought to the level of natural gas, which is 95-99%. Only then can biomethane be transferred to the general gas distribution network. There it is mixed with natural gas and used: to generate electricity; for heating purposes; at gas stations for cars. In addition, alternative fuels from waste are cheaper than purchased natural gas, which saves significant funds.

Organic waste from livestock complexes and the processing industry is already fertilizer in itself. However, the efficiency of such fertilizers is only 10-15% of the possible. When processing this waste in a biogas plant, there is a significant improvement in their properties and the formation of organic fertilizer – digestate.

Digestate is the residue of biogas production from organic mass. Biogas is formed as a result of organic matter methane fermentation. The gas is only 10% of the total production biomass. The other 90% of biomass comes for digestate. It contains such components as 2.3-4.2 kg/t of nitrogen, 0.2-1.5 kg/t of phosphorus, and 1.3-5.2 kg/t of potassium. This substance is similar to compost in its chemical composition, so it can be used as an additional fertilizer to increase soil fertility [4, p. 518]. Digestate improves crop health by providing additional nutrients and helping to maintain adequate soil moisture. If mineral fertilizers are absorbed only by 35-50%, then biofertilizers – by almost 99% [13, p. 27].

So, an average biogas plant, which is located at a livestock complex and processes about 37,000 tons / year of manure, after processing, gives approximately 35,000 tons of valuable biofertilizers per year. 1 ton of such fertilizers contains on average 3.5 kg of total nitrogen N (Table 2).

Biofertilizers (digestat) in many respects are several times better than other organic fertilizers (manure, droppings, peat):

1. Environmental impact on the soil. Organic fertilizers in unprocessed form cause more damage to the soil, polluting it and groundwater. Whereas digestat is an absolutely pure ecological fertilizer.

2. Lack of weed seeds. Pig and cattle manure and peat usually contains large amounts of weed seeds. 1 ton of fresh manure contains up to 10 thousand seeds of various weeds. This leads to a loss of yield from 5 to 7 centners of cereals per hectare.

3. The absence of pathogenic microflora, but the presence of active microflora, contributes to the intensive growth of plants.

4. Lack of an adaptation period. Biofertilizers (digestat), due to their shape, begin to work effectively immediately upon application.

5. Depending on the mineral fertilizer, digestate can be applied in any amount. When using it, there is no soil mineralization, since it is an environmentally friendly product.

Table 2

Chemical composition of digestate after processing in a biogas plant (liquid fraction 95% moisture)

Biofertilizers – digestate (fermented mass)	Chemical composition kg/t				
	N	$NH_4 - N$	P_2O_5	K_2O	MgO
Pig manure	3.1-3.8	1.4-2.0	2.3-2.4	2.1-2.4	0.5-0.8
Cattle manure	1.8-2.2	1.0-1.2	0.8-1.6	2.2-2.8	0.4-0.5
Bird droppings	7.1-8.2	3.0-3.5	6.8-7.9	5.0-5.6	1.5-2.2
Grass silage	2.2-2.8	0.9-1.5	1.9-2.3	2.0-2.5	0.5-0.7

Source: summarized by the authors

Enterprises of agro-industrial production, operating on a waste-free principle, are able to meet energy, environmental and economic requirements. For the introduction of non-waste technologies into practical activities in the field of the agro-industrial complex, a consistent policy of the state is necessary, which will stimulate (or even force) the preservation of primary resources and the use of secondary resources.

Based on the data of the Bioenergy Association of Ukraine, the authors have identified the top 10 most powerful biogas plants in Ukraine and the amount of electricity they produce in 2020 (Table 3).

According to the State Energy Efficiency Agency, at the end of 2020, there are 53 installations in Ukraine that generate energy from biogas and operate at a "green" tariff. The total installed capacity of such installations is 103 MW, which is 10 MW more than in the previous year (2019 – 93 MW), and almost 6 times more than at the end of 2015 (18 MW). Of these, 67 MW (23 installations) operate on agricultural waste (Figure 5).

In the Vinnitsa region, there are two powerful enterprises for the production of biogas from animal waste – LLC "Vinnytsia poultry farm" and

Table 3

Top 10 most powerful biogas plants in Ukraine in 2020

№	Enterprise	Region	Installed capacity, MW	Electricity production in 2020, million kWh
1	LLC "Teofipolska Energy Company"	Khmelnytsky	15.61	82.20
2	LLC "Vinnytsia Poultry Factory"	Vinnytsia	12.00	48.91
3	LLC "Korsun Eco Energo"	Cherkasy	7.50	36.73
4	LLC "Horodyshche-Pustovarov Agricultural Company"	Chernihiv	6.02	31.21
5	PJSC "Oryol-Leader"	Dnepropetrovsk	5.69	35.21
6	LLC "LNK"	Kyiv city	5.31	18.51
7	LLC "Cleaner Energy"	Kyiv	3.74	14.04
8	LLC "Yuzefo-Nikolaev biogas company"	Vinnytsia	3.20	18.52
9	LLC "Biogas-Ukraine"	Zaporozhye city	3.20	12.48
10	LLC "Kommertsbudplast"	Kherson	3.12	10.57

Source: summarized by the author based on the data of the Bioenergy Association of Ukraine [14]

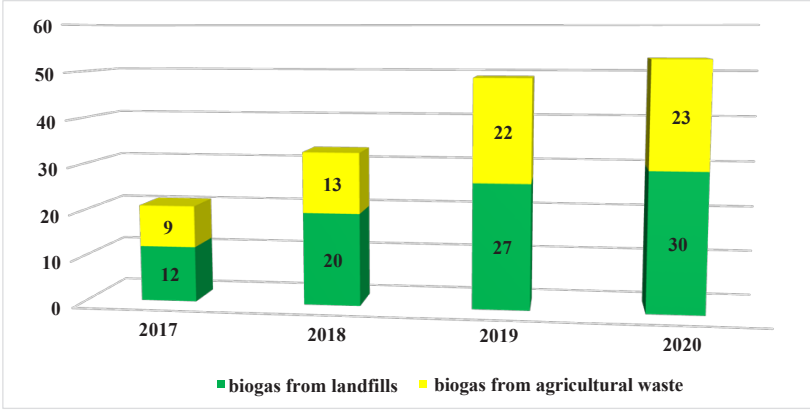

Figure 5. Growth dynamics of biogas plants in Ukraine, 2017–2020

Source: generated by the authors according to [15]

biogas from crop waste – LLC "Yuzefo-Nikolaevskaya biogas company". The region is not only a leader in the production of gross agricultural products, but can also become one of the leading ones in the implementation of waste-free technologies that provide a full cycle of recycling economy.

Due to the difficult socio-economic situation in Ukraine, it is difficult to implement too fast rates of introduction of non-waste technologies in agriculture and an increase in biogas production from crop and livestock waste, which causes a crisis of non-payments for the "green tariff" and an increase in the state's debt to operating biogas complexes 2020 with their reimbursement. However, we share the opinion of scientists from the Bioenergy Association of Ukraine regarding the forecast of the development of the bioenergy sector in terms of biogas production by 2050, given in Table 4.

Table 4

Forecast for the development of the bioenergy sector in 2050 in terms of biogas production in Ukraine

Year	Installed power		Biofuel consumption, millions of tons of oil equivalent	Substitution of natural gas, billion m^3	Reduction of CO_2 emissions, million tons / year	Investments, billion EUR	Job creation, units	
	MWel	MWt					min	max
2025	281	302	0.38	0.05	1.40	0.70	1.13	5347
2030	511	547	0.73	0.11	2.70	1.28	2.04	9702
2035	760	814	1.16	0.20	4.27	1.28	3.04	14441
2040	910	975	1.47	0.28	5.42	1.90	3.64	17297
2045	1073	1150	1.78	0.38	6.56	2.28	4.29	20390
2050	1385	1484	2.36	0.55	8.70	2.68	5.54	26324

Source: summarized according to the Bioenergy Association of Ukraine [14]

The ecological effect of biogas production is the safe processing of organic waste and animal by-products through methane digestion. In general, there are 5 main environmental effects from the introduction of biogas complexes at agricultural enterprises:

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

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

3) reducing the use of fossil fuels, saving resources and introducing alternative energy sources;

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

5) reduction of greenhouse gas emissions.

As indirect environmental effects, one can single out – prevention of pollution of ground and surface waters and soil.

Investing in biogas plants for large agricultural enterprises solves several problems at once. One of the most important is waste processing, which is especially important for livestock breeding complexes. The costs of dumping manure pollute the environment and harm the ecological situation, reaching hundreds of thousands. It is wiser to spend this money on the construction of a biogas plant. The resulting biogas will serve as fuel for the heating system, or will be used for other purposes.

Thus, in our country there are great raw material opportunities and favorable tariffs for electricity from renewable energy sources, since biogas is a promising direction for the development of green energy in general. Large livestock complexes can benefit from the complex benefits of the construction of a biogas complex: get rid of the waste products of animals and the costs of their burial; get fuel for heating industrial premises; get alternative fuel for gas-powered vehicles; generate and sell electricity at a green tariff; to sell the converted substrate as a highly efficient fertilizer.

6. Practical value

The introduction of waste-free technologies into production is one of the important aspects of the transition to a recycling economy, as well as an effective tool for protecting the environment, achieving energy independence of agricultural formations and obtaining additional economic benefits.

One of the ways is to use animal waste – excrement, urine and manure – as a source for biogas production. The construction of biogas complexes will allow, first of all, to reduce the cost of transportation and disposal of agricultural waste, especially animal waste. The advantage of biogas production is the approach of the industry to energy independence and obtaining additional economic benefits (biogas can be cogenerated into electrical, thermal energy or biomethane – an analogue of natural gas, as

well as reduce dependence on external energy carriers). Also, an important economic and agrotechnical effect from the introduction of waste-free biogas plants is the formation of organic fertilizers (digestate) in the process of anaerobic fermentation of biomass.

Also, agro-industrial activity is one of the largest sources of greenhouse gas emissions into the atmosphere, therefore biogas plants can be considered as the implementation of emission reductions within the framework of joint implementation projects (Kyoto Protocol, Paris Agreement). In many pig and cattle farms, manure is stored in anaerobic ponds, which results in methane emissions directly into the atmosphere. Reduction of methane emissions in biogas complexes will be achieved through the production of biogas with its subsequent combustion in a cogeneration unit. In addition, a reduction in emissions of another greenhouse gas, CO_2, will be achieved, since the generation of electricity and heat from renewable sources (biogas) will replace the equivalent amount of energy obtained from the combustion of fossil fuels in power plants that supply power to the grid.

Biogas production is economically justified and prevails in the processing of a constant stream of waste (effluent from livestock farms, slaughterhouse, vegetable waste). Cost-effectiveness lies in the fact that there is no need for advance waste collection, organization and management of their supply, while it is known how much and when the waste will be received.

The proliferation of biogas complexes in Ukraine, which has significant potential for the production of biological fuels, needs to be developed quickly and on a large scale. The production of biogas from agricultural waste, taking into account the successful world experience, would not only solve the problem of energy independence of the agro-industrial complex, but also make it possible to stabilize the economic situation in the industry and attract additional investment resources.

7. Conclusions

Effective waste-free production in the agricultural sector necessarily presupposes a balance between agricultural activities and the state of the biosphere. Environmental protection is an integral part of the process of introducing waste-free agricultural production into management practice, because the economic, environmental and social components of the existence of efficient production in the agricultural sector form a single

indivisible system. Understanding the scale and nature of environmental problems, their relationship with the conditions for the functioning of the agricultural sector allows us to determine the appropriate resources for their solution.

Based on the research, that the main task of introducing waste-free technologies at agricultural enterprises is the creation of closed production cycles with the recycling of raw materials, when each end link of one production serves as the initial link of the next, as a result of which no waste enters the external environment and negative consequences for the natural environment are minimized. Subject to the constant introduction of innovations, improvement of equipment and technologies, the development of low-waste and non-waste technologies allows the introduction of energy-saving and resource-saving technologies, is an achievement of modern economic development in the transition from a linear model of the economy to a circular model.

The use of innovative, environmentally friendly and economically sound technologies by enterprises contributes to a gradual increase in economic efficiency and production efficiency. An environmentally oriented highly efficient environmental management system at the enterprise will ensure the formation of a balanced development of both the enterprise and society as a whole.

Expansion of resource opportunities at the expense of waste should proceed from the determination of their resource value and the technological capabilities of their involvement in production, substantiation of directions and ways of the most efficient use of waste, creation of territorial production complexes with closed resource cycles based on resource and technological prerequisites, and the like. At the same time, great importance should be attached to the development and implementation of relevant state, regional, sectoral programs that are aimed at solving the most important environmental and resource problems, creating new approaches to solving waste problems and means of their implementation.

One of the most promising alternative energy sources is biogas – the only type of renewable energy that can be used in several ways. It can be burned in heating installations and received heat for heating. In its enriched form, it is used in automobile engines as a fuel. In cogeneration plants, you can get electricity, which is then sold or used in their own industries.

Ukraine has a large raw material potential for biogas production and significant opportunities for increasing the capacity of biogas plants. Recycling organic waste from production and consumption in a biogas plant is an economically and environmentally optimal solution. At the same time, the products formed as a result of waste disposal (biogas, biofertilizers) contribute to solving the problem of meeting the need for certain categories of material resources, namely energy resources and fertilizers, which will contribute to an increase in production volumes subject to a decrease in the use of natural resources. Substitution of energy carriers and fertilizers with biological analogs, which are achieved by recycling production waste into biogas, as well as a significant decrease in their imports, have a positive effect on both the internal equilibrium in the country and its GDP.

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