Scientific monograph

THEORETICAL AND PRACTICAL ASPECTS OF SUPPLY CHAIN MANAGEMENT, USING OF ECOLOGISTICS AND THEIR INNOVATIVE DEVELOPMENT IN THE CONDITIONS OF DIGITALIZATION OF THE ECONOMY

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Scientific monograph

Riga, Latvia
2023

UDC 33(08)
Th310

Title: Theoretical and practical aspects of supply chain management, using of ecologistics and their innovative development in the conditions of digitalization of the economy

Subtitle: Scientific monograph

Scientific editor and project director: Anita Jankovska

Authors: Svitlana Koliadenko, Svitlana Kiporenko, Illia Chikov, Valeriia Vovk, Oleksandr Shedlovskiy, Illia Liudvik

Publisher: Publishing House "Baltija Publishing", Riga, Latvia

Available from: http://www.baltijapublishing.lv/omp/index.php/bp/catalog/book/301

Year of issue: 2023

Theoretical and practical aspects of supply chain management, using of ecologistics and their innovative development in the conditions of digitalization of the economy: Scientific monograph. Riga, Latvia: Baltija Publishing, 2023. 188 p.

ISBN: 978-9934-26-286-9

DOI: https://doi.org/10.30525/978-9934-26-286-9

The monograph presents the results of research devoted to solving the modern scientific problem of substantiating the theoretical and practical aspects of supply chain management, the use of ecology and their innovative development in the context of the digitalization of the economy. The provisions on the impact of the digitalization of the economy on changes in the supply chains of business entities in the conditions of the post-COVID economy and military operations on the territory of Ukraine were further developed. Efficiency is substantiated and recommendations are developed for the introduction of waste ecology at agro-industrial complex enterprises and the transition to a circular economy model. A methodical approach to managing competitiveness in supply chains and their innovative development in the context of digitalization of agribusiness enterprises is outlined. The monograph is intended for a wide range of scientists, managers, specialists, graduate students, masters and students involved in the theory and practice of supply chain management at agribusiness enterprises.

The materials of the monograph reflect the results of the research carried out as part of the research work "Management of supply chains in the conditions of digitalization of the economy" (state registration number 0121U109445).

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THEORETICAL AND PRACTICAL ASPECTS OF USING WASTE ECOLOGISTICS IN SUSTAINABLE SUPPLY CHAINS OF AGRICULTURAL ENTERPRISES

Illia Chikov[1]
Valeriia Vovk[2]

DOI: https://doi.org/10.30525/978-9934-26-286-9-2

Abstract. In modern economic conditions, which are characterized by an increase in the impact on the environment, an increase in its pollution, the issue of introducing fundamentally new approaches to the implementation of the production process is extremely relevant.

A significant place in the processes of eco-destructive impact on the environment is occupied by pollution of atmospheric air, water basins and soils due to the formation and storage of agricultural waste. At present, the problem of accumulation of agricultural waste is becoming extremely important. It is agricultural waste that generates the largest amount of greenhouse gases that have a significant eco-destructive impact on the environment. According to the Food and Agriculture Organization of the United Nations (FAO) [1], agriculture and livestock in particular is the second largest sector emitter by emissions of greenhouse gases. Thus, livestock production produces about 18% of all anthropogenic greenhouse gas emissions in the world, in particular, methane emissions from this industry account for about 16% of the total annual emissions in the world, nitrous oxide – 17% of the total annual volume; as well as a number of other environmentally harmful substances and compounds.

For Ukraine, the issue of pollution from agriculture is extremely relevant, given the role of the agro-industrial complex in the country's

[1] PhD (Economy), Senior Lecturer
of the Department of Computer Science and Economic Cybernetics,
Senior Researcher of Scientific Subjects,
Vinnytsia National Agrarian University, Ukraine
[2] Postgraduate Student,
Assistant of the Department of Computer Science and Economic Cybernetics,
Researcher of Scientific Subjects,
Vinnytsia National Agrarian University, Ukraine

economy. According to the State Statistics Service of Ukraine, in 2020 Ukraine exported agricultural products worth $18.8 billion, which is almost 40% of all national exports. Among the livestock products, the largest part in Ukraine's exports is occupied by poultry products. According to the Ukrainian Club of Agrarian Business, in the first half of 2021, 51 thousand tons of chicken were imported, which is 18% more than in the same period last year. In value terms, chicken imports amount to about $22 million [2].

As a result of the activities of poultry farms, there is a powerful pollution of atmospheric air, water and soil. During the life of one chicken, 0.2-0.3 kg of litter is produced daily, a significant accumulation of waste from this industry without rational approaches to their disposal leads to an increase in the environmental burden on the environment.

The purpose of the study is to substantiate the theoretical and practical aspects of the use ecologistik of the waste in sustainable supply chains of agricultural enterprises. The subject of the study is the theoretical, methodological and practical aspects of applying the principles of ecologistik of the agricultural waste in sustainable supply chains for the transition to a circular economy model and waste-free production.

Methodology. The following scientific methods were used in the research process: monographic (when studying the theoretical aspects ecologistics of the waste and its role in sustainable supply chains); statistical (when analyzing the state of agriculture, assessing the role ecologistics of the waste to ensure waste-free production); settlement and constructive (when substantiating the management practice of resource conservation in the development of agriculture on the principles ecologistics of the waste); all kinds of techniques of the economic and statistical method (statistical observation, comparison, tabular, graphical); abstract-logical – to summarize the results and formulate the conclusions of the study.

The results of the study show that the most rational response to modern environmental threats from agriculture is the transition to a circular economy model. Therefore, today the issues of developing such an ecologistical system at agricultural enterprises that would minimize greenhouse gas emissions and provide resource-efficient ways for their processing or disposal are becoming extremely relevant.

Practical implications. Proposals have been developed to introduce aspects of ecologistics of waste in sustainable supply chains to ensure the energy autonomy of agricultural enterprises.

Value/originality. The application of the principles of ecologistics of waste in the activities of agricultural enterprises will allow working on the principle of waste-free (low-waste) production, that is, move to a circular economy model. This model is a system solution aimed at mitigating the negative impact of production and consumption on the environment, especially in the context of reducing greenhouse gas emissions and waste.

1. Introduction

Logistics as a field of practical activity makes its negative contribution to the state of the environment. Recently, ecological logistics has been used as a modern concept of logistics, which, within the framework of the concept of sustainable development, is considered as an effective approach to the management of material and accompanying flows with the aim of reducing ecological and economic damage caused to the environment. At the current stage of development, environmental science is actively developing and includes several promising areas of research (reverse logistics, «green» logistics, recycling logistics, waste disposal logistics, etc.).

The main task of ecologistics is to ensure the minimization of damage to the environment due to the restrictive conditions for the use of natural raw materials in the field of supply, production and marketing.

Ecologistics of waste is one of the subsystems of logistics management, which covers the return flow of unwanted deliveries and the movement of things such as reusable packaging that should be returned to the sender, recyclable materials and waste. Distinctive features of ecologistics of waste, which distinguish it from other types of logistics, are both the object of research (waste flows) and the direction of movement of the main flow – the reverse (from consumers to producers). Therefore, the object of ecologistics is the waste streams that appear as a result of the processes of production (for example, production waste, industrial effluents), distribution (for example, packaging and goods damaged during transportation) and consumption (return of unnecessary goods and packaging reusable). It should be noted that waste, as well as the final products of enterprises, appear at the output of their logistics systems.

Regarding the use of the principles of ecologistics of waste in agriculture, we note that the advantage is not only the reduction of the ecological load on the environment, but also ensuring the energy autonomy of enterprises and obtaining additional economic benefits by processing production waste into biofuels (in particular, biogas and bioethanol).

Thus, the inclusion of the principles of ecologization in the traditional issues considered by logistics allows to form an effective approach to the management of sustainable supply chains in order to reduce logistics costs and ecological and economic damage to the environment.

2. Analysis of recent research and publications

Ecologistics of waste (green logistics, reverse logistics, recycling logistics) in sustainable supply chains attracts the attention of a significant number of domestic scientists, such as Boiarynova K.O., Valiavska N.O., Hrechyn B.D., Davydenko V.V., Korniiko Ya.R., Kustrich L.O., Petrenko N.O., Sahaidak Yu.A., Kharchenko T.B., Tsymbalistova O.A., Chernikhova O.S., Yudenko Ye.V. and other.

Korniiko Ya.R. and Valiavska N.O. define the conceptual apparatus and stages of the development of ecologistics [3]; Boiarynova K.O. and Davydenko V.V. focus their scientific works on the methods and approaches of ecologistics to the development of waste-free production [4]; Grechyn B.D. characterizes the development of ecologistics as a process of activation of innovative activities of domestic enterprises [5]; similar scientific views are highlighted by Kustrich L.O. and Petrenko N.O., who characterize innovative forms of doing business in Ukraine based on the use of ecologistics elements [6]; Sahaydak Yu.A. and Kharchenko T.B. explore the prospects for the development of green logistics in Ukraine [7]; the problems of reverse logistics and the prospects for its development in Ukraine are devoted to the scientific works of Tsimbalistov O.A., Yudenko E.V. and Chernikhova O.S. [8].

In general, a number of scientists of the Vinnytsia National Agrarian University highlight in their works the methods of handling agricultural waste and the main aspects of implementing waste-free technologies for their utilization and production of biofuels from agrobiomass at agricultural enterprises. In particular, Kaletnik G.M. [9; 10; 18], Honcharuk I.V. [11; 12; 13; 18], Yemchyk (Honcharuk) T.V. [9$ 11], Tokarchuk D.M. [14], Palamarenko Ya.V. [15], Pryshlyak N.V. [14], Hontaruk Ya.V. [10; 13], Furman I.V. [16], Shevchuk G.V. [14], Kupchuk I.M. [17], Okhota Yu.V. [18] and others.

Paying tribute to the scientific heritage of scientists, today the issues of the essence of the concept of «ecologistics», the key aspects of the concept of this category as an innovative method of handling agricultural waste in sustainable supply chains to ensure the country's environmental and energy security have not been sufficiently studied.

3. Analysis of the volumes of generation and management of agricultural waste in Ukraine

Ukraine is a large agricultural country exporting a significant amount of agricultural products. The Ukrainian agricultural sector is an integral part of the global economy. Over the past 50 years, agricultural production has more than tripled due to: the technological contribution of the Green Revolution, which affected labor productivity and accelerated population growth. This increase in global production has put more pressure on the environment, up to the point of negative impacts on soil, air and water resources, with subsequent impacts on human health and the resilience of ecosystems at risk.

In 2021, the number of active enterprises engaged in agricultural activities is 70,803 units, while in 2010 the number of such enterprises was almost 10,000 more – 80,321 agricultural enterprises (Figure 1).

Agriculture produces an average of 23.7 million tons of food per day worldwide. The export of agricultural products of Ukraine in 2021 amounted to 27 billion US dollars. Agricultural and food industry products accounted for 40.7% of total exports of goods in 2021, which is 4.4% less than in 2020 (45.1%). According to the data of the Ukrainian Agrarian Business Club, the largest part of the Ukrainian export of agricultural products is crop production. In 2021, it accounts for 15.6 billion US dollars, or 56% of total agricultural exports. This indicator was achieved through the trade in grain crops.

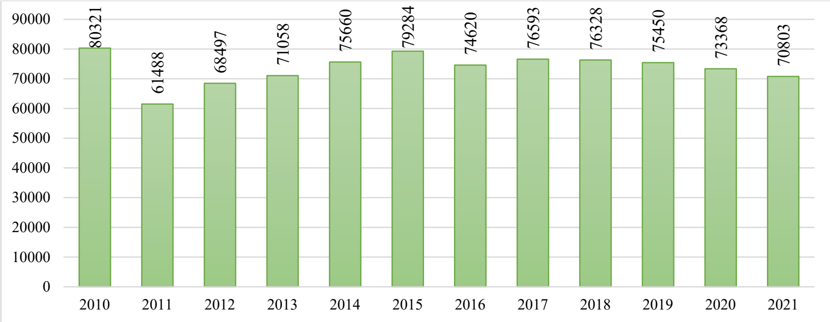

Figure 1. The number of active agricultural enterprises in Ukraine, 2010-2021, units

Source: compiled by the authors based on the data of the State Statistics Service of Ukraine [19]

The smallest export revenue came from the livestock sector. So, in 2021, these products were exported in the amount of 1.4 billion US dollars, which is only 5% of the total exports of agricultural products. Among the livestock products, the largest part in the export of Ukraine is poultry products [2]. As a result of the activities of poultry farms, there is a powerful pollution of atmospheric air, water and soil. During the life of one chicken, 0.2-0.3 kg of droppings is produced daily, a significant accumulation of waste from this industry without rational approaches to their disposal leads to an increase in the ecological burden on the environment.

The dynamics of changes in the volume of total exports of Ukraine and agricultural products, in particular, during 2010-2021 are shown in Figure 2.

Due to the constant growth in the volume of agricultural production by business entities in Ukraine during 2014-2020. (Figure 3) the volumes of accumulation of agricultural waste are constantly increasing (Figure 4) both in specially designated places and in places that are not suitable for waste storage. All this contributes to an increase in the logistics costs for transporting waste to specially designated places. Similarly, along with the increase in agricultural production, the increase in the accumulation of agricultural waste and the increase in the logistics of transport of agricultural waste, the volume of pollutant emissions into the environment is increasing.

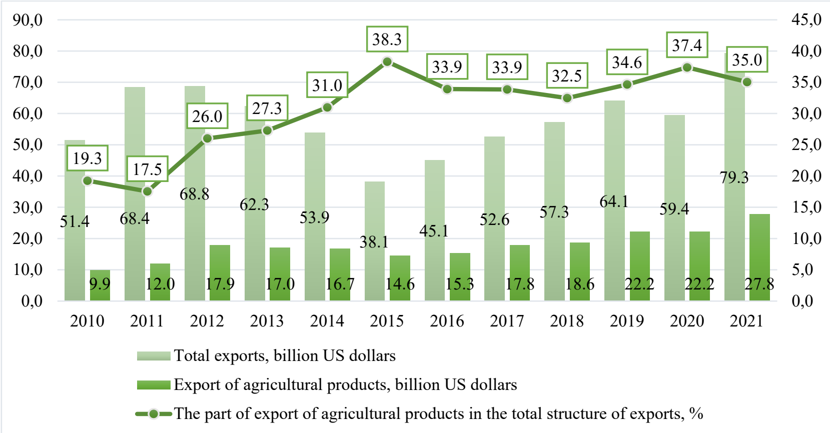

Figure 2. Dynamics of export of agricultural products of Ukraine, 2010-2021

Source: compiled by the authors based on the data of the State Statistics Service of Ukraine [19]

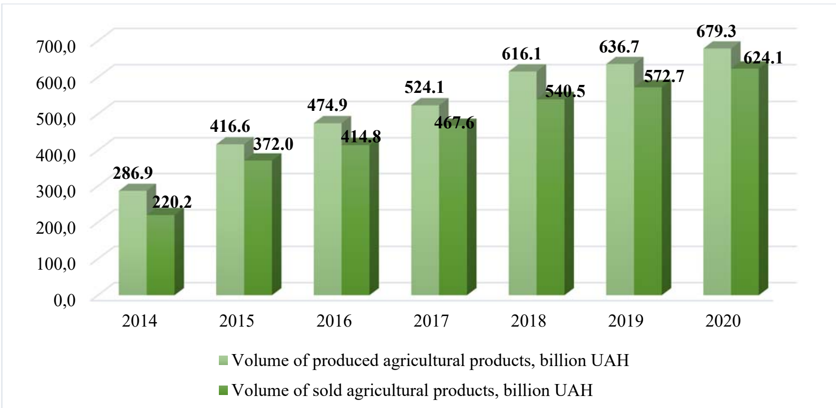

Figure 3. The volume of produced and sold agricultural products in Ukraine, 2014-2020

Source: compiled by the authors based on the data of the State Statistics Service of Ukraine [19]

Agricultural waste and by-products are usually the remains of plants or animals that are not processed into food or feed. They are non-food agricultural products and include animal waste (dung, animal carcasses), food processing waste, crop waste (e.g. corn stalks, droplets and selection of fruits and vegetables) and hazardous or even toxic waste (e.g. pesticides, insecticides and herbicides) [20].

They often create environmental and economic pressures in the agriculture and primary processing sectors, which can be exacerbated by regional specialization in both crop and livestock production. For example, high concentrations of manure in animal husbandry lead to bacteria pollution, large greenhouse gas emissions, and large loads of organic matter and nutrients (eg, nitrogen).

In Figure 4 summarizes the data on the volumes of agricultural waste generated during 2010-2020.

In recent years, agricultural waste (i.s. generated during agricultural production) has not exceed 2% of the total waste generated in the country. Despite this, agricultural waste is a source of air, water and land pollution, which leads to economic damage and social problems (deterioration of the health status and quality of life of the population).

Improper land cultivation, inefficient use of pesticides and mineral fertilizers – this leads to the formation of agricultural waste. Transport and industrial pollution and consumer attitudes towards land also have a negative impact. Fresh cattle and pig manure, as well as bird droppings, are particularly dangerous. If they are stored in closed storage facilities, as a result of biochemical reactions, harmful substances and gases are formed, such as amines, ammonia, nitrates and others. When livestock waste enters water bodies, the chemical properties of water are disturbed. Irreparable damage is also caused by residual fertilizers, pesticides, and emissions from agricultural machinery [21]. Key indicators of waste generation and management in Ukraine during 2010-2020 are given in Table 1.

However, agricultural waste and by-products can be converted into valuable resources through intensified conversion processes, resulting in new value-added products such as bioenergy, biofertilizers, biomaterials and biomolecules depending on the amount of biomass. Today, agricultural waste is considered a valuable secondary energy resource.

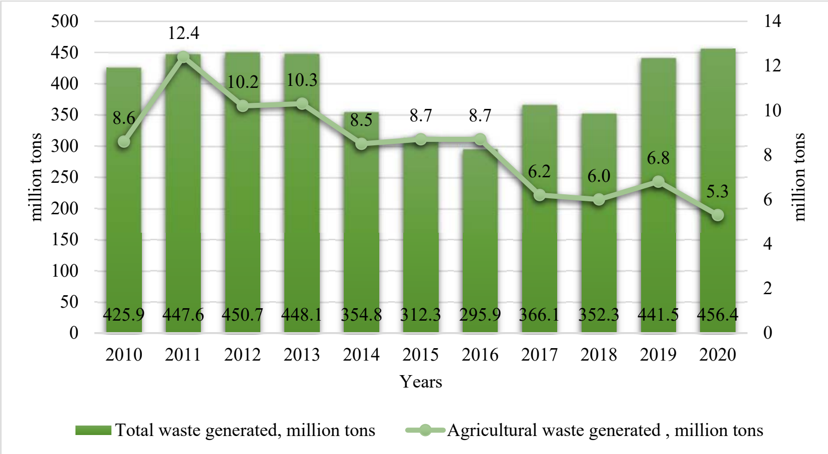

Figure 4. Volumes of agricultural waste generation (crop and livestock production) in 2010-2020, million tons

Source: built by the authors based on data from the State Statistics Service of Ukraine [19]

Utilization of agricultural waste is divided into two areas:

1. Regressive – does not bring economic benefits to the enterprise and is used when it is not possible to reuse waste.

2. Progressive – recycling of agricultural waste.

Consequently, today agricultural waste is, on the one hand, a source of environmental pollution, and on the other hand, it is this type of waste that is converted into energy and fuel in an environmentally friendly way, thus ensuring energy independence. The actual volumes of agricultural waste in Ukraine, more than 90% of which can be used in recycling processes, are many times higher than the figures given by official statistics. Under such circumstances, it is not possible to talk about the formation of an effective state system for waste management, which, in particular, would ensure the introduction of significant resources of plant and animal origin into economic circulation through waste recycling. Thus, in Ukraine there is a need to increase the efficiency of waste management of agricultural enterprises in accordance with European and world trends. A promising direction for the use of agricultural waste for energy purposes is the production of biofuels.

Table 1

Key indicators of waste generation and management in Ukraine, 2010-2020

Indicators	Years							Deviation, +/-
	2010	2015	2016	2017	2018	2019	2020	
Generated, thsd.t	425914.2	312267.6	295870.1	366054.0	352333.9	441516.5	462373.5	36459.3
Imported, thsd.t	4.1	3.4	7.9	112.0	89.4	22.0	2.7	-1.4
Total incineration, thsd.t	1058.6	1134.7	1106.1	1064.3	1028.6	1059.0	1008.0	-50.6
including for the purpose of receiving energy	840.3	1086.3	1035.3	1008.5	951.2	960.1	902.2	61.9
Utilization, thsd.t	145710.7	92463.7	84630.3	100056.3	103658.1	108024.1	100524.6	-45186.1
Prepared for utilization, thsd.t	-	1940.5	2920.5	3357.8	3193.6	2810.4	2641.3	-
Waste disposal to the managed dump-sites, thsd.t	313410.6	152295.0	157379.3	169801.6	169523.8	238997.2	275985.3	-37425.3
Disposal by other removal methods, thsd.t	24318.0	55248.1	39390.4	55360.1	57674.2	57503.1	46768.1	22450.1
Neutralized, thsd.t	-	2616.0	186.7	248.8	212.1	379.9	464.8	-
Placed on landfills, thsd.t	87.4	14.4	12.4	3.7	2.5	3.4	-	-
Exported, thsd.t	281.3	675.4	415.6	261.8	190.8	260.6	257.8	-23.5
Removed due to leakage, evaporation, fire, theft, thsd.t	1367.6	6.5	19.8	19.5	6.7	12.0	-	-
Accumulated waste during operation in waste disposal sites at the end of the year, mln.t	13267.5	12505.9	12393.9	12442.2	12972.4	15398.6	15635.3	2367.8
per 1 km^2 of the country, t	21984.2	21692.8	21495.6	21579.3	22498.9	26706.9	27115.9	5131.7
per person, kg	289236	291888	289274	292857	306896	366392	374457	85221

Source: calculated by the authors based on data from the State Statistics Service of Ukraine [19]

4. Agricultural waste management methods in Ukraine

Over the past few years, Ukraine has taken many steps to significantly reduce energy consumption, develop energy efficiency and renewable energy, which are the main measures to reduce greenhouse gas emissions.

According to the State Statistics Service of Ukraine, in 2020, in the structure of energy consumption of the agro-industrial complex of Ukraine, the largest part is occupied by oil products (1060 thsd toe), electricity (325 thsd toe), heat energy (174 thsd toe) and natural gas (122 thsd toe). The consumption of energy produced from coal and peat (5 thsd toe) and biofuels and waste (28 thsd toe) is an insignificant share (Table 2) [19].

Table 2

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

№	Types of fuel and energy	Years					
		2018		2019		2020	
		thsd toe	%	thsd toe	%	thsd toe	%
1	Coal & peat	7	0,37	7	0,37	5	0,30
2	Grude oil	-	-	-	-	-	-
3	Oil products	1190	62,40	1244	66,24	1016	60,51
4	Natural Gas	122	6,40	96	5,11	122	7,27
5	Nuclear	-	-	-	-	-	-
6	Hydro	-	-	-	-	-	-
7	Geotherm. solar etc.	-	-	-	-	-	-
8	Biofuels & waste	37	1,94	28	1,49	28	2,26
9	Electricity	333	17,46	316	16,83	325	19,36
10	Heat	219	11,48	188	10,01	174	10,36
Total		1907	100,0	1878	100,0	1669	100,0

Source: created by the authors based on data from the State Statistics Service of Ukraine [19]

Recycling of resources is not something new, and at the same time, it has not been a priority until now, since it is cheaper to obtain more primary resources and dispose of them after use. The greatest increase in the economic efficiency of the Industrial Revolution was achieved by using a significant amount of resources to reduce labor costs. Since the Industrial Revolution, mankind has followed a traditional linear model of production and consumption, which involves the extraction of necessary resources from the environment, the production of goods or services from them, and their consumption, along with the generation of waste at each stage. That is, in a linear model of the economy, raw materials are used to manufacture products, and waste is disposed of. In other words, a large amount of raw materials is used irrationally. The linear economy model is shown in Figure 5.

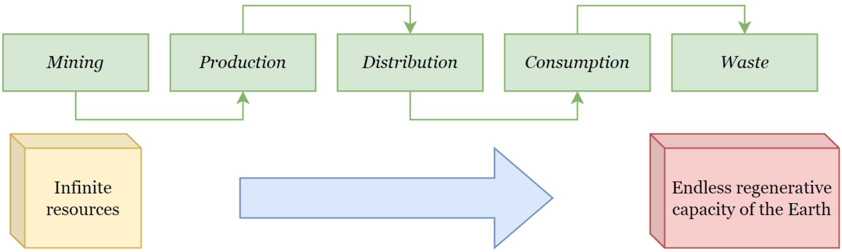

Figure 5. Structural diagram of the linear model of the economy

Source: developed by the authors

In the conditions of a rapidly growing shortage of natural resources, waste accumulation, environmental pollution (emissions into the atmosphere, waste disposal at landfills, ocean pollution), climate warming, etc., there is an awareness of the situation and the process of transition to a new economic model is launched, system-forming principles that allow minimizing the volume of primary resources, minimizing the volume of waste and the area of their storage. The most rational response to modern environmental threats from agriculture and energy security is the transition to a circular economy model [22]. The circular economy model is shown in Figure 6.

The issue of transition from a linear to a circular economy is primarily caused by an extremely high load due to the imperfection of the current linear economy business models, in which the main value is created by generating as large volumes of production and sales as possible. The main idea of the circular economy, in turn, is a rethinking of the philosophy of consumption, use and processing of resources.

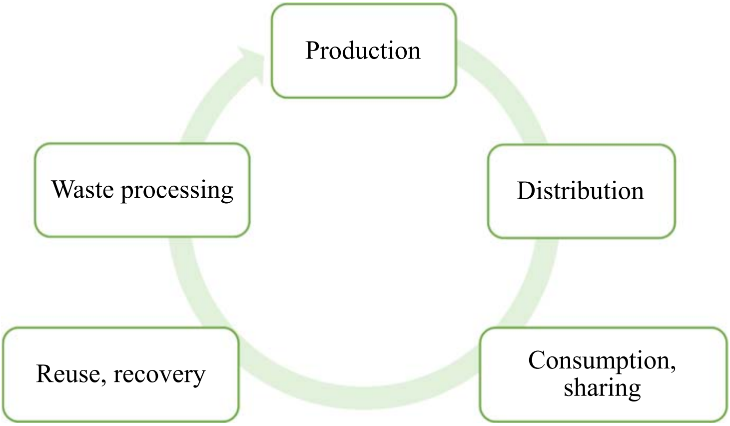

Figure 6. Structural diagram of the circular model of the economy

Source: developed by the authors

The circular economy is a model of production and consumption, including sharing (including leasing), reusing, improving, recycling, and recycling existing materials and products for as long as possible. It is aimed at solving global problems, in particular, climate change, loss of biodiversity, reduction or even elimination of waste and pollution, apparently, with the exception of thermal, which is not explicitly discussed within the linear economy. This is the fundamental difference between the circular model of the economy and the linear (it can be defined as traditional) model of the economy.

Traditional linear business models focus on profit maximization without regard to sustainable development goals and involve the extraction of resources, the production of goods and their sale to consumers. At the end of use, the products are incinerated or landfilled, and environmentally efficient disposal usually goes beyond linear business models and involves additional costs. In a narrow sense, the transition to circular business models leads to a shift in the focus of maximizing company profits to maximizing benefits for society and the environment.

The circular economy is a new economic model that emphasizes the reuse of materials and the creation of added value through smart services and solutions. This model is a system solution aimed at mitigating the negative impact of production and consumption on the environment, especially in the context of reducing greenhouse gas emissions and waste.

The circular economy is based on the ideas of maximizing the value of resources already received from the environment over several life cycles. That is, the circular economy is a transition from a wasteful system to a lean production system, which is built on the basis of a regenerating business model of the economy and provides promising opportunities for successfully addressing environmental challenges, increasing productivity, innovating, improving competitiveness, and stimulating economic growth and enterprise development.

If we consider the features of this model somewhat broader, then the circular economy is based on the principles of circular functioning of closed flows of materials, energy, waste, etc., that can be obtained through the reuse of waste products, thereby conserving natural resources and creating value for the elements of the system. Business models of the circular economy are based on the creation of value of the elements of the system due to the decrease in their cost, where the key attention is paid to the preservation of primary resources.

The principles of the circular economy cover the entire life cycle of a product from production and primary consumption to the disposal of waste and used products, while positive environmental and socio-economic effects are achieved through the reuse of products. It assumes that the value chain is organized in such a way that the outputs of one chain become the inputs to another, reducing dependence on new raw materials. That is, when a product reaches the end of its life, the materials from which it was made are stored in the economy as much as possible. This approach reduces the impact on the environment in two ways: firstly, people do not load landfills with waste; secondly, there is no need to process resources and their «return» to nature, that is, it is supposed to abandon the «processing for the sake of processing» approach, where the value of the final product can partially cover the costs of its production.

The practical focus of the circular economy is the preservation of the value of products through its continuous use. It is about extending the shelf life of products produced within a production system, making them more profitable and sustainable over time.

It is known that innovations are unique solutions leading to an increase in economic, social, environmental or other effect [23]. This thesis is fundamental in understanding the model of the closed cycle economy, which creates new, innovative business opportunities and, most importantly, creates the possibility of saving and reusing already expended energy, raw materials invested in production. This is achieved through an innovative, industrial and product process focused on sustainability and sustainable use of resources; maintenance and service support; reuse and sharing; restoration, recycling, etc.

The circular economy is focused on bridging the gap between production cycles and natural ecosystems by minimizing waste. It includes economic industrial approaches and regenerative systems of a wide range, in which losses, emissions, waste and leakage of energy, as well as the use of primary resources, are minimized by slowing down, «cycling» and narrowing material and energy flows.

Under this model, value is maintained longer: waste and resource use are minimized, and materials are reused through recycling, thereby generating a higher value for the final product. This encourages manufacturers to design products in a special way to ensure their repeated and long-term use. It is a production and consumption model that indirectly influences and modifies production processes and promotes reuse through the repair or recycling of items, thereby increasing the sustainability of production and consumption. This contributes to the prevention of irreversible climate change, biodiversity loss, air, soil and water pollution through the use of resources at a rate that exceeds the Earth's ability to restore them.

The circular economy suggests the use of business models that improve the resource and energy efficiency of the production and consumption of goods, as well as achieve a reduction in the negative impact on the environment. Within the framework of a closed economic model, business processes are focused on ensuring the sustainability and environmental friendliness of the system itself through the implementation of measures to minimize not only environmental, but also economic and social impact. Within the linear economic model, in turn, the focus is on minimizing the environmental impact for the production of a unit of production, and the processing of residual resources, as a rule, creates products of lower quality compared to primary products, which accordingly reduces the value of the material and complicates it further reuse.

The business processes of the circular economy are based on closed cyclic ecosystems, where waste, as such, does not exist, because any residual resource can be used to create a new product, and the fewer stages of processing the resource goes through, the higher the value of the final product. Thus, in a circular business model of the economy, the stocks of resources in the system of production and consumption constantly circulate to maintain their maximum value and utility, and the fluctuations of these stocks are in equilibrium with the environment, which ensures their sustainable use. At the same time, business processes during the passage of product life cycle stages are designed not only for the circulation of resources, but also for maintaining the conservation and regeneration of the biosphere in order to eliminate hazardous emissions and prevent the degradation of natural resources [24].

The idea of a circular economy is not only to reduce waste downstream of a product's life cycle, but also to apply innovation along the entire value chain of a product. According to this model, technologies for minimizing the use of natural, material, energy resources and ensuring the possibility of their reuse are supposed to be integrated into the production process already at the stage of its creation. This creates a closed supply chain that maximizes added value throughout the entire product life cycle.

The circular economy is based on the 3R approach («reduce» – «re-use» – «recycling»), according to which waste from one production process can become a valuable resource for other processes (Figure 7).

The 3R concept describes the international strategic directions of greening, aimed at reducing the volume of waste generation (reduce), reuse of waste (re-use), as well as the use of waste as secondary raw materials (recycle). At its core, the 3R approach is nothing more than a basic model of sustainable development, where the priority areas are minimizing the consumption of primary raw materials, maximizing the use of secondary resources and their long-term reuse [25].

The 3R concept was replaced by the 6R approach, or rather, it can be considered a more complex and detailed version of 3R. The concept of 6R implies the inclusion of directions for greening and increasing the sustainability of production based on a system of circulation of products over several life cycles, while the understanding of the basic elements of 3R has been expanded.

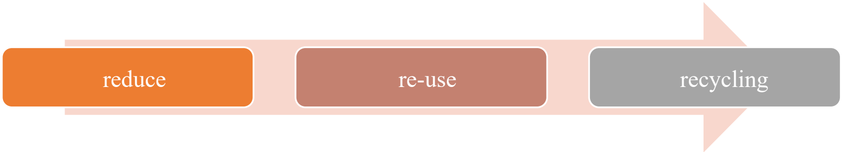

Figure 7. A systematic approach to understanding the circular economy

Source: constructed by the authors based on data [25]

On Figure 8 shows a closed-loop, full-life cycle manufacturing system based on the 3R concept and an extended treatment of the 6R processes, which ensures a continuous flow of materials while relying on the optimal use of energy, raw materials and other resources, and (optimally) produces a minimum amount of waste and emissions.

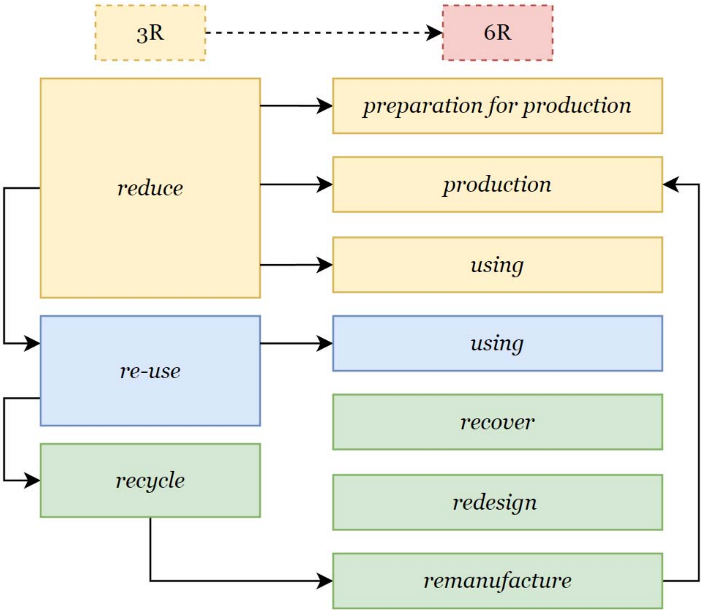

Figure 8. Concept of 3R-6R circular economy

Source: developed by the authors based on their own research

Within the 6R, recycle includes the reuse of waste for the same purpose, as well as the return of waste after appropriate processing to the production cycle. In industry, for the totality of waste and discharges, the processing operation is called recovery, for powdery, pasty waste – regeneration, for discharges and emissions – recycling. Reduce mainly focuses on the first three stages of a product's life cycle and refers to reducing the use of resources in the pre-production phase, reducing the use of energy, materials and other resources in the manufacturing process, and reducing emissions and waste in the use phase. Reuse refers to the reuse of the product as a whole or its components after the completion of the first life cycle in order to reduce the use of primary resources and materials in subsequent cycles. For example, goods that were used or commission goods. Recovery is the process of collecting products and components at the end of their use, disassembling, sorting and cleaning for use in subsequent life cycles. May involve reprocessing or repairing already used products and components to restore them to their original condition. For example, extraction and repair of components from equipment for further use. Redesign – the process of developing next-generation products that use components, materials and resources removed from the previous life cycle or products of the previous generation (redesign in order to use as many removed components and parts as possible without losing functionality). Remanufacturing (rebuilding) is the repetition of the production cycle of production based on the original product specifications using repaired or new parts. For example, when a car is factory rebuilt using old or new parts.

The key to implementing the 3-6R principles is, of course, innovative technologies. At the same time, we are talking not only about technologies that ensure the safety of the disposal of household and industrial waste or increase the possibility of processing secondary resources, we are talking about technologies for increasing efficiency along the entire chain of the production process: raw material extraction – transportation – production – consumption – disposal. That is, about biotechnologies as the basis for strengthening the country's food and energy security, ensuring the environmental sustainability of agricultural production and the processing industry.

It should be noted that in 2018 the World Economic Forum significantly expanded the principles of the circular economy to 10R (Figure 9).

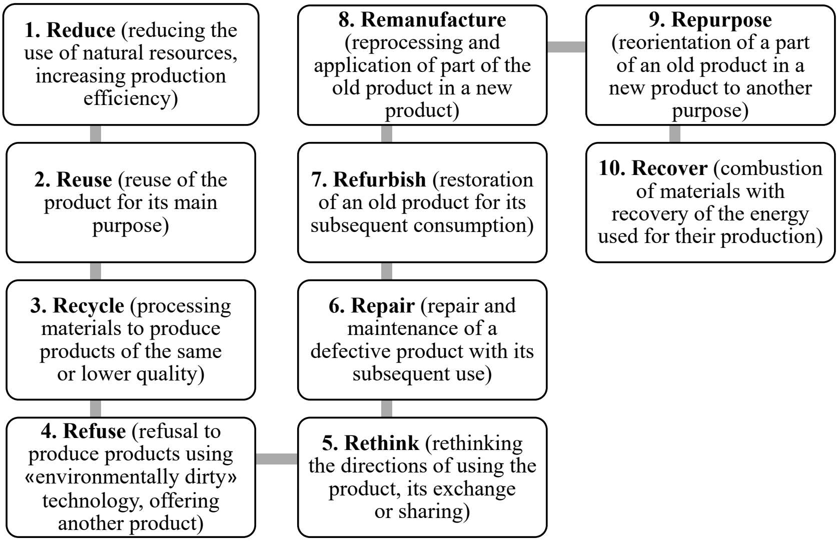

Figure 9. Basic principles of circular economy (10R model)

Source: summarized by the author based on his own research

The circular economy is based on three main components of the economic system – resource providers, waste processors, sources of utility and advocates the reuse of resources to create, supply and consume manufactured products. An analysis of the best international experience in the development of the principles of a circular economy shows that the state and non-governmental organizations, the scientific and business community, as well as citizens take part in the creation of institutional and market conditions.

The transition to a circular economy model should be accompanied by changes in the institutional environment, the economic basis of production and consumption, digital transformation and the introduction of the best technologies. All changes must occur at the micro-level of an individual enterprise and product, the meso-level of sectors of the national economy and industrial complexes, and the macro-level of an individual state or region.

Table 3

Conditions for the development and functioning of the circular economy

Subject	Characteristic
State	Strengthening of environmental legislation
	Development of a step-by-step strategy for the development of the circular economy
	Financing programs and initiatives in the field of circular production and consumption
Non-governmental organizations	Initiation of the formation of unions and alliances of private-state partnership in the field of development of circular practices
	Inclusion of interested parties in the network of socially and environmentally responsible business and consumption
Scientific community	Research in the field of new products and materials that minimize the impact on the environment
	Development of justifications for the feasibility of circular economy development
	Development of educational programs and training of personnel for circular production
Business community	Financing of internal projects of companies regarding the expansion of producer responsibility
	Implementation of best available technologies and circular business models
Citizens	A conscious choice of eco-friendly products
	Participation in separate collection and sorting of waste at the household level
	Formation of circular models of consumption

Source: developed by the authors

Macro-level indicators are useful to support decisions in areas such as the harmonization and integration of economic, trade and environmental policies, strategies and programs for sustainable development, waste management and resource storage. As a rule, the main emphasis at this level is on the mutual influence of the economy and the environment. Macro indicators describe the characteristics of a country or a larger region, mainly related to its interaction with the rest of the world through material, energy and trade and economic flows.

Meso-level indicators allow for more detailed monitoring and analysis of material flows within the country's economy, distinguishing between industries, production sectors and consumption sectors. Meso-indicators are focused on the industry, industry, consumption activity or level of a particular material (energy), thus helping to identify material losses, pollution sources and efficiency improvement opportunities in specific production and consumption sectors. They describe the economic, environmental or social indicators of a region, industry, sector or group of certain products (raw materials).

Micro-level indicators provide detailed information for decision-making at the level of specific processes, products, business or at the local level. Micro-level indicators ensure the implementation of policies and decisions in sectors such as energy efficiency and integrated waste management, product-specific strategies, etc. They describe the economic, environmental or social performance of a municipality, product or company.

Within the framework of the circular economy, the issue of waste management is one of the highest priorities. Waste management (or waste disposal) includes the processes and actions necessary to manage waste from its creation to its complete disposal. This process includes the collection, transportation, treatment and disposal of waste, as well as the monitoring and regulation of the waste management process, as well as the laws, technologies and economic mechanisms associated with them.

When creating a waste management system, it is important to choose a method for handling them. Most of the countries here follow the principles of waste management hierarchy. According to them, all types of recycling and reuse of waste as resources are optimal for the purposes of the circular economy and the environment, various methods of processing with energy production follow, and the last alternatives that do not comply with the concept of sustainable development are waste disposal with a minimum impact on the environment.

Separate collection is of key importance in the waste management system. The organization of this process is a complex task, including economic, legal and social components, separate collection is possible only with close cooperation between the state, business and society.

The circular economy is an integral part of the ecological economy and is aimed at maintaining the value of products and resources for a long time of their use by returning the latter to the production cycle while minimizing waste generation, while reducing the environmental impact of humans on the environment. Ecological economics has a number of basic provisions, among which the key is the environmental conduct of business (social responsibility); ensuring sustainable development; popularization of an ecological way of life and integration of the principles of «isolation». The directions of the ecological economy should be formed based on the goals of sustainable development. As you know, by 2030 the countries of the world, including Ukraine, are pursuing the goal of achieving 17 sustainable development goals (model 17R), some provisions of which are closely related to the principles of the circular economy.

Table 4

Levels of penetration of circular economy business models

Realm	**Levels of penetration of circular economy**		
	Micro-level	**Meso-level**	**Macro-level**
Production	eco-friendly production; application of repair, modernization, remarketing of products; dematerialization (providing services in online format)	creation of territorial industrial symbioses, eco-settlements; use of «green» supply chains and reverse logistics	creation of national industrial symbioses; standardization of structures and systems
Trade	sale of finished products; provision of complex services for the use of finished products	creation of regional markets for secondary resources, products as services	creation of national markets of secondary resources, products as services
Consumption	repair and maintenance of purchased finished products by the consumer	development of a territorial waste management system	development of a national waste management system
Waste management	use of disposal processes	creation of a waste trade market	creation of eco-cities

Source: developed by the authors

Based on the above, the circular economy can be considered as an innovative approach to the organization of logistics processes based on the closed movement of resources with their minimum losses through waste and the maximum involvement of secondary resources in production in order to achieve sustainable development of logistics systems (Figure 10).

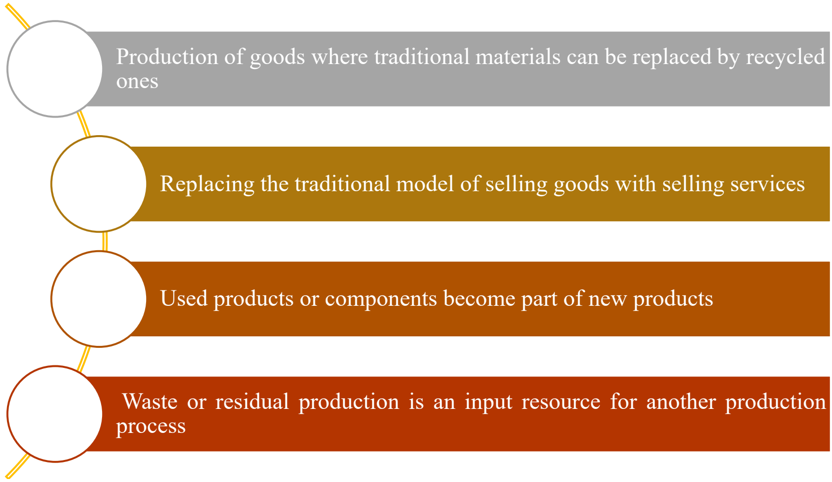

Figure 10. Directions of the circular economy

Source: developed by the authors based on their own research

In a global sense, the circular economy is very relevant, because, according to international organizations, the global value of the circular economy market is more than a trillion US dollars. In addition, the transition to a circular economy will form the basis for generating enormous opportunities for the modernization of production and the introduction of industrial innovations, providing an annual GDP growth of 7%.

Business models of the circular economy are gradually being introduced into everyday life, and recycling tools and technologies are becoming more widely available. In particular, major cities are adopting new ecosystems and biotechnologies to reduce their environmental footprint by reducing waste, recycling resources, and producing cleaner energy.

Thus, in connection with the active development of the circular provisions of the economy, special business models have been developed aimed at minimizing the consumption of materials and resources for the production of economic benefits; extending the life of the product through refurbishment or repair; benefiting from end-of-life materials and products by recycling them. The main tools of the circular economy model based on the principles of sustainable development are environmental innovations and biotechnologies.

In a circular economy, business models focus on the rational use of raw materials, which can only be used through the synthesis of various business models, where the emphasis is shifted from the sale of products to the provision of services. An example of this is the «Product as a Service» model, in which consumers take on a product that can be provided free of charge or at a discount, and the consumer pays only as a function of the product received, depending on its use. This approach encourages manufacturers to create a product with a longer life cycle. The Resources recovery model is based on the use of technological innovations in the recovery and reuse of resources, which ensures the elimination of their losses by reducing waste and increasing the profitability of manufacturing products from reverse flows. This model is most suitable for enterprises that produce large volumes of by-products and have the ability to effectively recover and process waste.

An interesting model is the Sharing platforms – the model is based on the exchange or sharing of goods or assets. Provides promotion of platforms for interaction between users of the product (individuals or organizations), thereby increasing its use. Of interest to manufacturers with low product utilization or underutilized capacity. This business model has led to significant changes in consumer relations (C2C – consumer to consumer), business and consumer (B2C – business to consumer), and has significant potential in the field of business-to-business relations (B2B – business to business) because it allows potential competitors to collaborate on sharing fixed costs, increasing asset utilization, generating revenue from equipment sharing, and improving overall efficiency. The Product life extension model allows companies to extend the life cycle of their products by repairing, upgrading, refurbishing or refurbishing. More suitable for industrial equipment manufacturers, where new models provide a slight increase in performance compared to previous ones.

Another example is the Circular Suppliers model, in which scarce resources are replaced by fully renewable sources. The model is based on long-term research and development, provides for the provision of fully recyclable or biodegradable resources that form the basis of a circular system of production and consumption. As a rule, the leaders of the economy in implementing this model are such industries as the automotive industry and energy. The above business models can be used alone or combined into more high-performance and complex processes. However, it should be noted that none of these models in itself is the only right way to address sustainable development issues and does not guarantee a closed production cycle. Much depends on the product market, suppliers and partners of the entire supply chain. Markets for various products are also at different stages of development, and these models are overwhelmingly a benchmark for modeling relationships in the «new» circular economy.

The introduction of the concept of a circular economy, in particular the practical implementation of the above models, is accompanied by social, economic and environmental consequences (Table 5).

Table 5

Effects from the implementation of circular economy business models

Social Effects	Economic Effects	Environmental Effects
Growth in the number of jobs	Reduced consumption of resources and energy	Reducing greenhouse gas emissions
Rising living standards	Formation of new sectors of production	Reducing the area of landfills for waste
Production and consumption of eco-friendly products	Growth of innovativeness of enterprises	Waste-free production and consumption

Source: developed by the authors

Speaking about the benefits of moving to this model, this process will achieve such environmental effects as reducing CO_2 emissions, reducing waste, reducing the consumption of scarce resources. The economic effects include: reduced costs for raw materials and energy, environmental taxes and fines; creation of markets for «green products». Social effects include the organization of new jobs, the formation of more friendly environmental behavior and social responsibility among the population.

An analysis of the circular economy business models discussed above shows benefits for both businesses and consumers. In particular, we are talking about the long-term benefits of enterprises due to the optimization of material flows through the introduction of closed-loop processes, expanding the scope of after-sales customer service.

Along with the application of these models, it should be noted the need to develop a system of «circular» criteria and environmental requirements in order to influence the supply chain. These are criteria aimed at improving durability, resource efficiency, product recovery and modernization, the possibility of reuse and the purchase (sale) of secondary raw materials.

The proposed system of criteria and requirements is given in Table 6. It should be noted that in Ukraine most of the listed criteria are applied in practice and become widespread.

Table 6

Criteria and resource requirements in a circular economy

Criteria	Requirements
Durability	Requirement of quality and durability standards
	Requirement of minimum warranty and availability of spare parts
Resource Efficiency	Requirements for the amount of energy consumption during operation
	Fuel consumption requirements
Reuse	Requirements for the supply of products in reusable containers / packaging
Restoration (conversion)	Modernization of machinery, equipment, system elements, etc.
Waste processing	Requiring the use of materials and products with low or no hazardous materials to improve the recyclability of these products and their packaging
	Requirement that, after use, products can be dismantled for recycling
Purchase of processing products	Purchase of textiles containing recycled fibers, paper with a share of recycled paper in its composition
	Requirement to contain a minimum percentage of recycled material in packaging

Source: suggested by the authors

According to the World Circular Gap Report 2021, in 2020 the global economy used only 8.6% of resources as secondary raw materials, only two years ago this figure was 9.1%, respectively, the situation has worsened significantly. The world is still dominated by outdated practices based on the principles of the linear model of the economy «take-make-throw away». The circular economy ensures that with fewer materials and energy costs, we can still provide the same or even higher production volumes. Thanks to the developed strategies and the reduction of resource consumption, the circular economy is able to reduce global greenhouse gas emissions by 39% and the introduction of primary raw materials by 28% [62]. To achieve the ultimate goal – the creation of a socially just and environmentally safe space, it is necessary to rationally use resources that will limit consumption and reduce emissions, keeping them within acceptable planetary boundaries.

Despite the development by the European Commission of the Circular Economy Action Plan in the framework of achieving the goals of the European Green Deal, each European country has national features in the implementation of the concept of a circular economy.

In particular, Germany, with a strong industrial economy, has formed the basis of a circular economy through material flows and the availability of materials, while the Netherlands has built on innovations in materials and business models. Finland is the first country in the world to develop a national roadmap for the transition to a circular economy. Scotland became the first country to join the Circular Economy 100 (CE100) club, created at the initiative of the Ellen MacArthur Foundation to stimulate cooperation and innovation for the development of a circular economy [63].

In China, the circular economy began to develop as part of the industrial ecology program, which considers how the waste of one company can become the resources of another. Turkey is also starting to implement the concept of a circular economy.

With the support of developed countries, some developing countries are just beginning to explore the possibilities of a circular economy. The governments of Rwanda, Nigeria and South Africa are actively cooperating with the World Economic Forum through the African Circular Economy Alliance.

There is a certain risk that developed countries and companies will use the circular economy model, introducing their technological advantages as an excuse to gain market access and guarantee the retention of their share. But, in our opinion, lower income countries can be considered more circular than developed countries, as there are greater savings in both resources and materials used. Therefore, the main question that needs to be addressed is how to turn these processes into an opportunity for sustainable development [61].

Recently, researchers have developed the concept of a circular bioeconomy, which is based on the sustainable and efficient use of raw materials from a variety of biomass, including waste. Some authors consider circular bioeconomy to be the intersection of two concepts – bioeconomy and circular economy. However, the circular bioeconomy is also considered to be more than these two models taken separately.

Note that the bioeconomy is a «green» economy, which is aimed at improving the well-being of people and ensuring social justice, in parallel with this, at reducing the burden on the environment [26]. In its simplest sense, the green economy is the means and methods aimed at ensuring the generation of low levels of emissions into the atmosphere and the efficient use of resources, which is in the interests of the whole society and ensures its sustainable development without harm to the environment. Actually, the introduction of advanced technologies as bioinnovations, based on the results of fundamental research in biological and molecular biological areas of bioeconomics, formed the basis of a new vector of economic development – bioeconomics, as based on knowledge in science, technology and innovation aimed at sustainable development.

Bioeconomy refers to the kind of activity that uses biotechnologies, that is, based on biological sources, materials and processes, to shape sustainable economic, social and environmental development. The use of biotechnologies creates the basis for the formation of a bio-oriented economy as a system that uses biological resources to produce high-tech products [27].

Today, biotechnology is one of the most technologically advanced sectors of the world economy. Biotechnologies form the basis for ensuring the rational use of natural resources, waste-free production and reducing the anthropogenic impact on the environment. The field of biotechnology as a modern direction of research in bioeconomics is designed to solve the key problems of the intensive use of natural resources, while maintaining a balance in the system of relationships «man – nature – society».

Today, four types of biotechnologies are distinguished depending on the scope of their use [28]:

1) blue biotechnologies – the use of aquaculture products for the production of ecological products;

2) white biotechnology – the introduction of bioprocesses into the production of biochemistry, biopharmaceuticals, food ingredients in order to make the industry more environmentally friendly;

3) green biotechnologies – the introduction of agro-industrial biotechnologies, including renewable energy produced from agricultural residues;

4) red biotechnologies – the production of medical equipment (development of new types of diagnostics and therapy) based on the use of the results of genomics and proteomics.

The field of biotechnology is an interdisciplinary area of scientific and technological progress that has emerged at the intersection of biological, chemical and technical sciences, where the synthesis of natural and engineering sciences makes it possible to fully realize the capabilities of living organisms or their derivatives for the creation and modification of products for various purposes. Biotechnology in agriculture is the industrial use of biological processes based on the production of highly effective forms of microorganisms, cell cultures and tissues of plants and animals with desired properties.

As mentioned above, biotechnology is a field of human activity, which is characterized by the widespread use of biological systems of all levels in various fields of science, for example, in industrial production, medicine, agriculture, etc. (Figure 11).

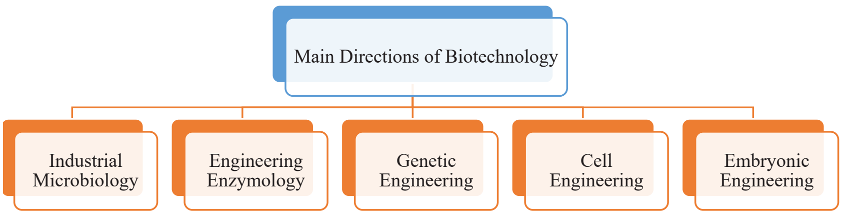

Figure 11. Directions of modern biotechnology

Source: author's research

In the agricultural sector of the economy, biotechnologies form the basis for strengthening the country's food and energy security, ensuring the environmental sustainability of agricultural production and the processing industry. It should be noted that biotechnology is most widely used in the field of agriculture, primarily due to the widespread use of various microorganisms capable of carrying out various biochemical reactions.

Biotechnologies in agriculture are divided into three priority areas: biotechnologies in crop production (plant protection, increasing productivity and precocity), biotechnologies in animal husbandry (survival of young animals, accelerated weight gain, increased resistance to diseases, increased milk yield), biotechnologies in the field of disposal (waste of cattle, pig breeding, crop production, etc.). The most effective biotechnological solution in the field of agriculture, which can reduce emissions and reduce the anthropogenic impact on the environment, is the production of biogas from the processing of biomass and wastewater. For the treatment of wastewater, natural water bodies and soil, the properties of some organisms are used to accumulate organic and inorganic compounds or certain chemical elements in their cells.

Plants, like animals, have innate defense mechanisms against various insects and diseases. Currently, scientists are actively searching for compounds that would activate these natural mechanisms without harming the environment. Within the framework of this biotechnology, great prospects open up for the creation of new biopesticides, such as microbial proteins and fatty acids, toxic to certain agricultural pests, but harmless to humans, animals, fish, birds and beneficial insects. The unique mechanisms of action of biopesticides provide protection against pests that are resistant to traditional agents. Reducing the pesticide and herbicide load means less risk of toxic contamination of soils and groundwater. In addition, biotechnological methods also make it possible to increase the efficiency of the assimilation of essential microelements by plants.

The above can be achieved through active innovation activities within agri-food enterprises in the direction of biotechnology development through the introduction of low-waste and waste-free production technologies; development of systems for the reuse of production waste; organic farming and safe food production; reduction in the use of mineral fertilizers in excess of the norms, pesticides, pesticides and other plant and animal protection products [29].

The circular bioeconomy also exploits the untapped potential stored in millions of tons of biological waste and residual materials. Most countries see the bioeconomy as a strategy to reduce dependence on fossil fuels, switch to renewable energy sources and ensure sustainable economic development.

The concept of a circular bioeconomy involves the use of biorefineries that process renewable bioresources, including agricultural waste and by-products, to produce energy (biofuels, electricity, heat) and various products such as food, animal feed, chemicals, pharmaceutical products, etc. Such facilities may use a variety of biological resources, including lignocellulose, algae (microalgae), agricultural, municipal, industrial and forest waste and residues such as, for example, manure, food, sediment.

One of the most effective green technologies is waste-free (ecophilic) technologies for processing agricultural waste into biogas, which allow not only to maximize the extraction of valuable components of raw materials and turn them into useful products, but also to minimize or even eliminate environmental pollution. The introduction of non-waste technologies at agricultural enterprises using production waste is the most promising direction for the transition to a circular bioeconomy model.

Entering a new level in the field of technical and energy solutions forms the basis for changing the emphasis of traditional biomass combustion on its impact using microbiological and other special methods. The use of biomass as a fuel obtained from waste from agricultural and industrial production, as well as household activities, is a new phenomenon in the direction of resource conservation. Biomass used for energy purposes must be produced in compliance with sustainable development criteria. Such criteria imply the prevention of a negative impact on the environment, the promotion of the economic development of the country and the region, the conservation of biological diversity, etc. Bioenergy installations save resources and remove part of the energy deficit in agricultural areas, in the field of small-scale industrial activity, in everyday life, etc., and can become a basic element in the system of a regional energy strategy.

Biomass has the advantage of being renewable and relatively cheap compared to conventional fuels. The convenience of using the potential of biomass and household waste is quite significant, since raw materials in the form of bedding and various types of waste are available throughout

Ukraine [30]. Modern biotechnological solutions make it possible to process almost any biological waste, such as bagasse, straw, manure, etc. to biogas as a source of energy.

Biomass is considered one of the key renewable energy resources of the future, as it provides 14% of primary energy consumption. Biomass consumption is growing rapidly. Globally, by 2050, biomass could generate 3,000 TWh of electricity, which would meet the needs of 7.5% of the world's population and help reduce CO_2 emissions by up to 1.3 billion tons per year. In turn, Sweden and Austria provide 15% of the need for primary energy from biomass, and the United States – 4%. The heat generating capacity of dry biomass is about 14 MJ/kg [31].

Currently, more than 65 countries around the world use biogas plants, producing biogas as an alternative energy source. The leader in the application of biogas technologies is China, where more than 15 million biogas plants operate. 86% of China's biogas is produced from agricultural waste, and only 14% from industrial and sewage waste. China has a mid- and long-term renewable energy development plan to achieve an annual biogas production level of 50 billion m^3, which should be provided by both industrial-type biogas plants and small-scale home plants.

There are about 10 million biogas plants in operation in India. Agricultural waste (including animal manure, farm waste, plant residues and energy crops) is the driving force behind the global biogas market. They make up approximately 65-70% of the raw materials of the biogas market.

According to the State Agency for Energy Efficiency and Energy Saving, the use of only 37% of waste from the work of livestock and crop farms will make it possible to obtain more than 10 billion m^3 of gas. In Table 7 shows a list of possible substrates (agricultural waste) for biogas production.

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

Table 7

The potential for biogas production from agricultural waste

Substrate	Dry Substances (DS), %	Dry organic matter (DOM), %	Specific output of biogas (SOP), m³/t	Specific output of biogas, m³/t
By-products of crop production				
Corn silo	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: created by the authors based on data from the Bioenergy Association of Ukraine [32]

Thus, the circular economy has a huge potential for solving environmental and economic problems. The transition to this concept will contribute to reducing the use of energy resources of the earth, reducing the cost of production. The creation of «green» markets and new business models will provide new jobs. It is this concept that is a universal alternative to the linear economy, which will make it possible to achieve a sustainable state in all spheres of human life and preserve life on our planet.

5. Theoretical foundations of ecologistics and its role in sustainable supply chains

In most cases, the term «logistics» is used to describe the process of transportation, storage, production of material flows, that is, when they move from the primary source of raw materials, through the production system to the final destination. Despite the fact that this term is used in various fields of activity, it still has many different definitions and concepts. However, logistics as such has become a key factor for the economic development and social welfare of our country. Of course, in the process of evolution and understanding of the essence of logistics, the main, and in many cases, the only goal has become organizing logistics processes in such a way as to maximize its profitability and speed up related processes. At the same time, no one paid due attention to the issues of components that affected the deterioration of the environment (deterioration of air quality, noise, vibration, etc.).

Logistics, the main task of which is the effective management of material and associated flows, has a significant negative impact on the natural environment, which necessitates the active use of its scientific and methodological apparatus to eliminate the harmful environmental consequences of logistics processes and operations. In order to ensure the sustainable development of transport, social, political and economic requirements are put forward, which involve reducing the level of negative impact on the natural environment of the entire supply chain. Therefore, logistics, environmental protection and natural resources are closely interconnected today.

In order to identify the level of impact of logistics on the environment, we suggest considering separate functional areas of logistics (Table 8).

According to the above, among the existing diversity of logistics systems, the greatest damage to the environment is caused by transport logistics. We will remind you that transport logistics is a system for organizing delivery, namely the movement of any material objects, substances, etc. from one point to another, using the optimal route.

It should be noted that the transport logistics of Ukraine is the main component of the general logistics system, which helps:

1) form market service areas, forecast and process the flow of materials and resources, as well as perform related work for the purpose of operational management and regulation of the logistics flow;

2) to develop a system thanks to which it is possible to organize the transport process (plans of transportation, distribution of the type of activity, formation of cargo flows, schedule of movement of vehicles, etc.);

3) manage stocks, transport, information, etc. and their maintenance and management.

In the modern sense, logistics is a scientific discipline (or a type of practical activity) related to planning, organization, management, control and regulation of material and information flows in space and time from their original source to the final consumer. In Figure 12 shows a conceptual diagram of logistics.

Table 8

The impact of individual functional components of logistics on the environment

Functional component of logistics	Environmental impact
Supply logistics	increasing the amount of solid waste in the process of storing material resources
	contact of people with environmentally hazardous ingredients during the processing and loading of goods
	anthropogenic load on soils during the storage of material resources and their delivery from suppliers
Information logistics	electromagnetic radiation during the transmission of information by technical means of communication
Sales logistics	increase in the volume of solid waste in the process of implementation
	spillage, leakage, evaporation of goods due to poor-quality packaging
Production logistics	increase in the use of production resources
	use of land plots for placement of production facilities and storage of production waste
	increase in noise and vibration in the surrounding area
Transport logistics	emissions of harmful substances into the atmosphere by vehicles
	the use of cheap types of fuel, the processing products of which have a negative impact on the environment and human health
	noise and vibration pollution
	the use of road transport, with the possibility of using sea, river or railway transport

Source: summarized by the authors based on their own research

Krykavskyi E.V. the emergence of megatrends, which can directly influence the course of logistics processes and are reflected in enterprise strategies (Table 9) [34], was investigated.

The main criteria for the economic efficiency of logistics activities are the indicators of expenses and distribution of funds in various technological cycles of logistics, as well as the organization of the flexibility of supply and distribution systems according to such parameters as time, accuracy and reliability of supply. Storage systems, used transportation methods, features of the production process, etc. are also evaluated. Among the main economic goals to which logistics tasks correspond are cost minimization; optimization of capital investments and procurement costs; ensuring system-wide efficiency and expanding coverage of distribution systems of markets and territories; use of heavy cargo and air transport, socially significant infrastructure components; reduction of production costs, in particular due to savings on environmental protection measures; placement of warehouses on the territory of enterprises (including places of storage of ecologically harmful and toxic raw materials, waste); transportation of large batches of goods by economical modes of transport. At the same time, organizational and economic tools, which are formed taking into account the principles of ecologically sustainable development, acquire the main importance.

Today, taking into account the environmental factor is a necessary condition for the integration of the Ukrainian economy into global economic processes in order to ensure its competitiveness. Ukrainian enterprises face the important question of the need to be aware of environmental priorities during production and economic activities. That is why the introduction of the latest technologies, raising environmental awareness, culture, compliance with the requirements of generally accepted environmental standards, and the search for effective tools for the implementation of ecological and economic management of enterprises, territories and regions are a necessary component of the country's future sustainable development. Therefore, the issue of developing such an ecological system at agricultural enterprises that would allow minimizing emissions of greenhouse gases and providing resource-efficient ways of their processing or utilization are becoming extremely relevant today.

The practical implementation of the principles of ecologically sustainable development of economic socio-economic systems determines the need to improve the methods, methods and tools of production organization based on the environmentalization of the logistics management system. It became obvious that it is necessary to reorganize the economy in such a way that human industrial activity is fully integrated into an efficient ecological infrastructure. In this context, a special role is played by the development and integration of digital technologies into the business processes of the economy, that is, the process of digitalization of the economic system should be one of the ways to modernize the traditional logistics system into an ecologically oriented one. There is a digital transformation of the production process, from the point of view of approaches to the production and sale of products, through the digitization of processes that are system-forming in the economic activity of enterprises. Digitization of the economy and business processes will make it possible to reduce production, marketing and sales costs; improve value chain management and improve the internal functioning of business entities; create new sales markets and expand customer service [35].

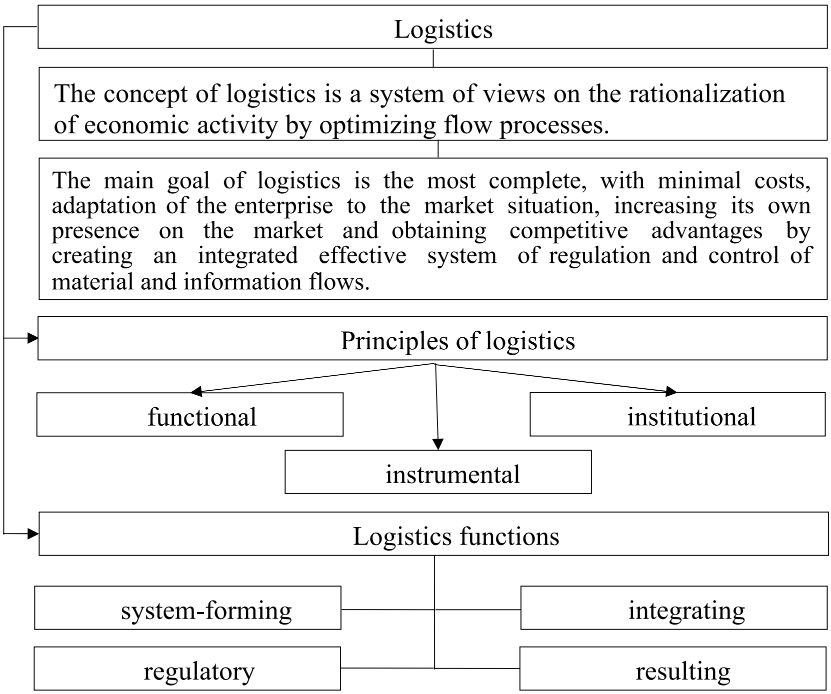

Figure 12. Conceptual diagram of logistics

Source: [33]

Table 9

Megatrends and their impact on logistics and enterprise strategies

№	Megatrends and their characteristics	Logistics and strategies
1	Globalization. The trend-oriented nature of globalization is continuous, as it covers the spheres of procurement and supply, production, distribution, provision of logistics services, trade and service, communication and communications. The spread of globalization processes is accompanied by a significant complication in the space-time plane of the transformation of material flows and information flows, which places new demands on logistics: its rationalization with the aim of reducing aggregate costs and risk costs while guaranteeing a high level of supply service, the introduction of modern supply systems	Deregulation and standardization → Mass production (standard products) → Mass distribution → Cost leadership management strategy → Logistics chain consolidation strategy
2	Individualization. Individual ordering of goods and services, non-standard and specific execution of orders, projects, etc. Significantly complicates logistics processes, primarily transport-warehousing, information, packaging, and this causes an increase in relevant costs, and therefore in general logistics costs	Self-realization and variety → Variety of special problems → Special performance of actions for customers → Differentiation strategy → Strategy oriented on individual problem solving
3	Informatization. Modern logistics decision-making technology and a resource flow management tool in real time, tools for modeling real logistics processes, a method of transferring, transforming, storing and using information	Control over processes and communications → Elastic production → Elastic distribution → Niche strategy → Strategy of optimal processes
4	Ecologization. It is also directly related to logistics: environmentally safe storage and disposal of waste, their reuse, disposal, disposal of used products, containers, packaging, which causes a significant increase in relevant costs. In supply chains, it is possible to implement the concept of recycling, improve the packaging system, optimize the transport component of logistics costs	Ecology and society → Products, «friendly» to the environment → Distribution, «friendly» to the environment → Logistics systems as a solution to the problems of ecology → Strategy oriented to society

Source: [34]

An ecological approach to economic activity is now an important condition for the sustainable development of the world economy. Logistics, without which it is impossible to imagine agricultural production and sale of products, is related to the movement of transport flows and processing of goods, which a priori is a type of activity that pollutes the environment.

The modern supply chain has become inextricably linked with concern for the environment and sustainable development. The overall objectives of the supply chain include the simultaneous achievement of economic, environmental and social performance. The main drivers of designing a sustainable supply chain are divided into three categories: internal, customers/suppliers, and third parties (Figure 13). A closer look reveals three important interrelated components:

– explanatory theory of implementation: this refers to theories and frameworks developed to provide a comprehensive understanding and/or explanation of aspects of implementation;

– the guiding model of the implementation process: the guiding process describes and/or translates the implementation into practice;

– evaluation of implementation: meets the measurement criteria – to determine the goals of implementation and success.

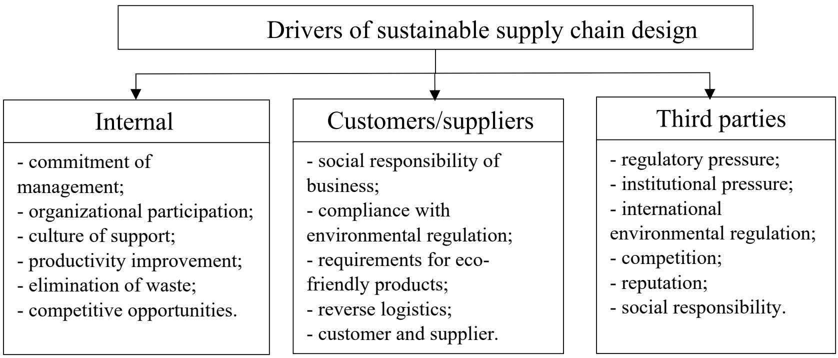

Figure 13. The main drivers of sustainable supply chain design

It is customary to measure the productivity of sustainable supply chains using certain indicators, which are grouped into three groups: environmental, economic, and social indicators (Figure 14).

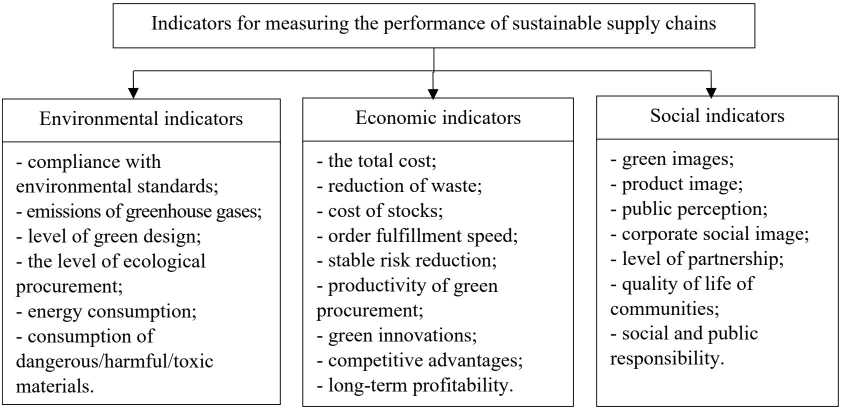

Figure 14. Performance measurement indicators of sustainable supply chains

The analysis of the development of the theory of logistics made it possible to determine the directions of application of logistic tools to solve ecological and economic problems of nature management (Figure 15).

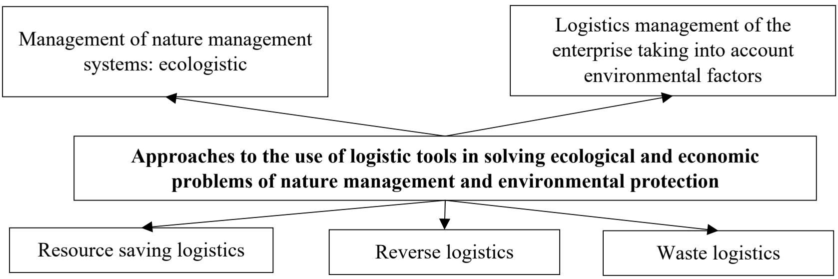

Figure 15. Directions of development of logistics on ecological and economic grounds

If we consider the complex logistics process taking into account the environmental factor, then the formation of the material flow should begin with earlier stages than in traditional logistics, namely: with the receipt (mining) of raw materials and materials, taking into account the methods of their extraction and development, as well as damage assessment , which is applied to the natural environment by intensive nature use.

In the following stages, in particular, storage and transportation, logistics flows are supplemented with information on the environmental friendliness of storage and transportation technologies for raw materials, materials, and finished products. At the stage of production logistics, information is received about production technologies, energy and resource consumption of production, quantity and quality of generated waste, pollution, technologies for their secondary use and disposal. The material flow at the output of the logistics system includes all components of the product life cycle, and the accompanying information flows – all information about the material flow.

Since part of the waste can be returned to production, and those that cannot be reused are subject to safe disposal, then we can talk about the cyclicality or closure of logistics processes based on the environmental factor. In order to ensure a high degree of environmental protection, it is necessary to introduce environmental management systems into logistics systems at all stages of the movement of material flows.

The main structural elements of the logistics management system are: goals, tasks, objects, methods, tools and principles of management. Along with the traditional mechanisms for the implementation of logistics management tasks related to the production and delivery of products or services with the lowest costs in the allotted time, ecologically-oriented management is characterized by some features due to the inclusion of an ecological component (Table 10).

Thus, the main conceptual provisions of logistics find a constructive reflection in the mechanisms of ecological regulation of nature use, thereby forming a new ecologically oriented («green») logistics.

According to the international survey «The Green Trends Survey» («Green Trends») in the study «Towards Sustainable Logistics» [36], 59% of business structures estimated that the «green» transportation of their products will be a decisive factor in winning customers in the future. Accordingly, in the coming years, most consumers will prefer a company that uses «green» transport as a logistics solution.

Environmentally oriented («green») logistics involves the integration of various business functions related to resource flows to achieve the goals of ecologically balanced, sustainable development. Logistics, through a complex of organizational and economic measures, allows to ensure the solution of resource conservation tasks, which led to the formation of a corresponding scientific direction in industrial logistics – ecologistics.

Table 10

Elements of the implementation mechanism of ecologically oriented logistics management

Element	Characteristic
The main goals and objectives of ecologically oriented logistics management	1) ensuring environmental safety and ecological and economic efficiency of logistics activities; 2) development of the requirements of the enterprise's environmental policy and creation of a mechanism for bringing elements of the logistics system into compliance with these requirements; 3) identification and assessment of the negative impact of logistics activities on the environment; 4) development of target indicators of ecological and economic efficiency and an action program for their achievement; 5) prevention of negative anthropogenic impact on nature in the process of production, consumption and disposal of manufactured products;
Objects of ecologically oriented logistics management	1) resource and energy flows of the logistics system; 2) information, financial, service and other flows of the logistics system related to the environmental aspects of the enterprise's activity; 3) flows of waste, garbage, harmful emissions, pollution; systems of physical distribution of direct and reverse material flows;
Methods and tools of ecologically oriented logistics management	1) reengineering of logistics system elements; 2) environmental management and audit; 3) processing of materials; 4) methods of reducing the resource intensity and energy intensity of the logistics system; 5) methods of increasing the level of environmental culture and personnel education; 6) various forms of interaction of business, state and public structures in solving environmental problems;
Principles of ecologically oriented logistics management	1) accounting for environmental features at all stages of the product life cycle and at all stages of material flow in the supply chain; 2) timely solution of environmental problems at all stages of movement of the material flow; 3) acceptance of responsibility for environmental consequences arising from the adoption of management decisions at any level; 4) the priority of solving environmental problems.

Source: developed by the authors

The scientific direction of «ecologistics» emerged relatively recently and concerns scientific research in the field of logistics of secondary resources, logistics of processing, as well as management of reverse supply chains. In today practice, the concept of «ecologistics» has many different definitions.

In general, ecologistics is interpreted as waste logistics, which defines measures that involve the implementation of the most rational solutions for collection, storage, disposal and management, or environmental protection and waste disposal. The logistics system of waste management covers all stages of the life cycle of waste, including its identification, collection planning, direct collection, preparation for use, ensuring its useful implementation and management of all stages of the chain.

Ecologistics is defined textually ambiguously, but practically identically in terms of content – as a logistics activity based on the principles of development, which takes into account the factors of environmental pollution, safety, etc. At the same time, different definitions emphasize different aspects of such activity.

Ecologically oriented logistics aims, first, to minimize the harmful effects of logistics processes on the environment; secondly, to reduce or completely eliminate the consumption of non-renewable or partially renewable energy resources. Achieving the goal of ecologistics management is possible through the integration of the principles of the circular economy, in particular the closed cycle, which involves the reuse of raw materials and materials that the company receives through the implementation of the main production cycle.

Ecologistics includes all types of activities related to the environmentally effective management of direct and reverse flows of products and information between points of production and consumption [37]. The ecologization of company logistics is especially relevant in the era of transition from a linear economy to a circular model economy or a closed-loop economy, as a self-renewing system, due to the removal of a rigid cause-and-effect relationship between growth (production) and the need for resources.

The field of ecologistics includes environmental projects for the construction of warehouses using energy-saving technologies and environmentally friendly building materials; minimization of thermal energy costs while ensuring safety and loading and unloading of goods; the use of reusable containers and packaging; increasing the carrying capacity of vehicles; provision of utilization processes in the form of reverse supply chains (collection and sorting of waste, their delivery to distribution warehouses, delivery of finished products obtained from waste to the retail network, etc.).

In order to improve the quality of logistics, with the help of its «ecologization», enterprises need to systematically approach the traditional logistics currently implemented and pay attention to its main subsystems: supply logistics, information logistics, production logistics, warehousing logistics, distribution logistics, transport logistics. Each of these directions involves the introduction of special technologies within the framework of the ecologization strategy (Table 11).

Table 11

Directions of using innovative technologies in ecologistics

Directions of ecologistics	**Characteristic**
supply logistics	technologies for the manufacture and use of ecological packaging
information logistics	creation of ecological centers, information hubs, digital supply chains
production logistics	energy and resource-saving production technologies, environmental reporting
warehousing logistics	use of robotics, digital guides, warehouse automation system
distribution logistics	cargo sorting system, automated route management system
transport logistics	use of electric cars, drones, environmentally friendly fuel; «ecological» modernization of engine parts

Source: developed by the authors

Such innovative technologies play a special role in ecologization logistics. Only thanks to the comprehensive digitalization of society, within the framework of the integration of two directions (ecologization and digitalization), it is possible to implement projects with a high level of innovation at enterprises. This will ensure the dynamism and stability of business processes of enterprises to the requirements of the external environment, as well as the formation of strategic behavior based on an innovative approach, with the aim of increasing competitiveness in the long term [38].

We consider the following to be the main technologies in ecologistics activities:

1) selection of suppliers of raw materials with the lowest costs of non-renewable resources;

2) reducing stocks to reduce the need for warehouse space;

3) optimization of cargo transportation routes in order to reduce emissions of harmful gases;

4) transition to eco-friendly modes of transport (sea, water, rail) and reduction of road transport;

5) exclusion from the logistics chain of intermediate points of storage and transshipment of goods;

6) reduction of paper document circulation.

The practical application of «green» logistics tools involves the implementation of processes for optimizing the functioning of the enterprise's logistics system in order to reduce the level of negative impact on the environment. From the position of the logistics approach at the enterprise, the following areas of optimization can act as green logistics tools:

1) in the field of procurement logistics, there is the use of environmentally safe containers and packaging, which after use are considered as secondary raw materials, which are collected at the enterprise and transferred to specialized enterprises for further processing;

2) in the field of production logistics, the use of eco-friendly materials, the introduction of closed production cycles and the organization of the collection and processing of production waste;

3) in the field of transport logistics, the use of environmentally friendly modes of transport or transport technologies, which provide for the minimization of emissions of pollutants into the environment, in the distribution of products.

The process of implementing «green» logistics tools should be reflected in the company's development strategy (Figure 16).

The general direction for all fields of the enterprise's activities within the framework of green logistics is to focus on the transition of the enterprise from the use of traditional materials (plastics, oil-containing materials, polyethylene, etc.) to the consumption of such raw materials and materials that are characterized by a low level of toxicity in relation to the environment.

In order for ecologistics to have a positive impact on business development, it is necessary to implement it correctly and be able to manage it effectively. Thus, the main directions of progress in the field of ecological logistics, which are used in the management of various material flows at enterprises, include:

1) division of business into its component functional business processes and gradual introduction of «new» principles of logistics;

2) development of recommendations for evaluating economic efficiency when making rational decisions using the basic principles of ecological logistics;

3) development of proposals to improve the legislative framework in the field of transportation and storage of products, taking into account the requirements in the field of environmental protection and environmental safety.

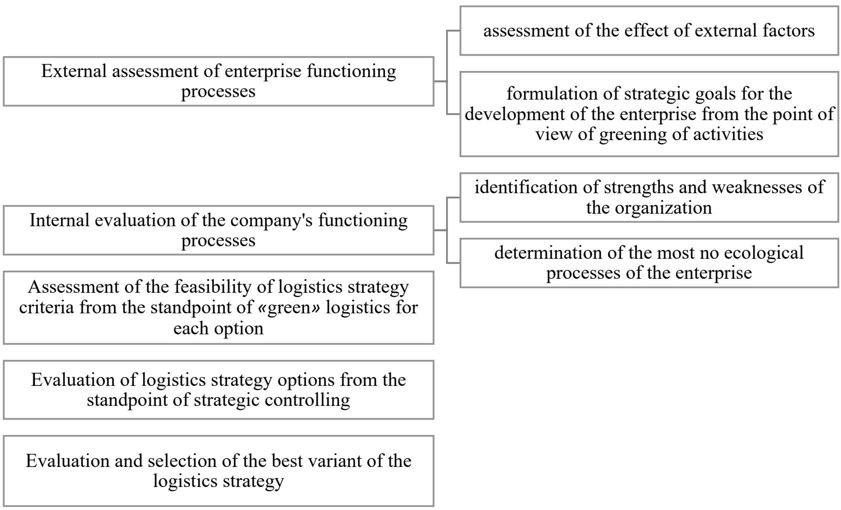

Figure 16. Development of ecologistics strategy options

Source: developed by the authors

Such measures are designed to improve the environmental situation in the country and direct the operation of enterprises through resource and energy conservation and respect for the environment. For enterprises, this will be an incentive to modernize production technology with the aim of minimizing waste and the possibility of using it as secondary raw materials, as well as returning this waste to processing operations.

Many domestic enterprises have already implemented the principles of environmentalism in their activities, and the following factors influenced their decision:

1) increasing the share of informed consumers and their desire to use ecological products;

2) a jump in the development of «green» logistics abroad. Domestic companies simply need to support this development, at least in connection with the great competition on the world market;

3) formation of a single ecologically oriented system capable of accelerating many processes both inside and outside the organization.

But, despite this, the use of the basic principles of the ecological component of logistics is a significant competitive advantage for many Ukrainian enterprises and for the country as a whole, since this vector of development is one of the most prioritized within the framework of the transition to a circular economy.

The spread of green technologies in our country, which usually includes various innovations in the processing and secondary use of materials, wastewater treatment, energy saving, air pollution control, etc., in general, can lead to the development of the following relevant areas of activity:

1) an increase in the level of investments in various programs and pilot projects related to the construction of new logistics and information centers capable of helping to increase the efficiency of logistics companies and freight transportation;

2) the use of specialized automated systems at the country's busiest warehouses, which will lead to the rational operation of the entire warehouse and its further reduction to optimal dimensions by optimizing transportation chains;

3) development of the country's transport system, as well as optimization of transport junctions;

4) increasing the share of using ecological transport when transporting a large amount of cargo, as well as reducing the share of ground transportation, which will reduce the harmful impact on the environment;

5) development and stimulation of waste processing, reduction of disposal tariffs.

When applying ecological logistics at enterprises, as well as during the creation of supply chains, the following desired results can be achieved:

1) rational use of resources belonging to the enterprise: secondary processing of waste and raw materials, introduction and use of recyclable packaging, use of natural energy, such as solar energy, and as a result, reduction of energy consumption from artificial sources;

2) conducting motivational programs to increase the interest and involvement of small and medium-sized businesses in this area using regulatory and legal tools;

3) training of personnel on environmental issues at enterprises engaged in the production of goods;

4) increasing the share of informed consumers, their motivation to purchase eco-products;

5) rejection of paper document circulation by automating typical tasks;

6) increasing the level of environmental safety, reducing the level of damage to the environment due to the use of all the above-mentioned methods and technologies of «green» logistics.

The use of waste is an urgent issue for ecologistics, since the accumulation of waste is a global environmental problem, the harmful impact of which on the environment is increasing rapidly over time. Ecologistics solves this problem in the following areas:

– external packaging (use of reusable packaging materials or their rapid processing, use of reusable containers, etc.);

– transport and warehouse waste (restoration, processing or burning of worn out car tires, batteries, motor oils and lubricants using specially developed technologies; reuse or repair of warehouse equipment: pallets, racks, boxes, etc.);

– disposal of vehicles (implies the use of the «repair-reuse-recycling» scheme at the end of the life cycle of vehicles).

Implementation of the principles of ecologistics provides advantages both for the enterprise and for the environment in general. Foreign companies have considerable experience in the functioning of ecologistics within the enterprise. The experience of many companies shows that there are usually differences between the commercial goals of the company and the city in terms of ecological logistics. However, the increase in the speed of the international exchange of goods and the strengthening of the elements of global exchange stimulates leading international corporations to introduce innovative technologies of «green logistics» into their own activities, which, on the one hand, has a significant beneficial effect on the image component of these companies, and on the other hand, contributes to the preservation of the environment.

Thus, among the international companies that successfully implement the concept of «green» logistics, DHL (Germany) can be singled out – it introduced the GoGreen service and keeps records of CO_2 emissions during the transportation of all cargo; UPS Air Cargo, an express delivery operator (USA) – uses cars with a hybrid engine; Deutsche Bahn Schenker Rail (Germany) – implements the Eco Plus project and obtains electricity for its electric locomotives from renewable energy sources; Green Cargo Road & Logistics AB (Sweden) – uses energy-saving locomotives; Toyota (Japan) – widely uses wind turbines and solar panels to generate electricity; K Line, a shipping company (Japan) – developed an innovative computer system for optimizing the operation of engines based on monitoring of weather and hydrographic conditions, which leads to a reduction of harmful emissions into the atmosphere by 1%; the Heineken company (Germany) was chosen for the analysis of the implementation of «green» technologies in logistics as one of the leaders in the world among businesses with a direction of sustainable development and social responsibility.

The above-mentioned experience of foreign enterprises in implementing greening solutions in their logistics activities allows us to highlight the key objects of logistics solutions and greening measures for these objects in the enterprise's logistics activities, which have already been successfully implemented in practice (Table 12).

The experience of the leading countries of the world proves that improving the environmental and economic status of the company is possible thanks to new logistics management methods. They require more detailed research and reform, therefore, the creation of such production management, which in its activities will be focused on environmental aspects, is of quite urgent importance.

Table 12

Implementation of eco-strategies in the logistics activities of the enterprise

Objects of logistics solutions	Environmental measures
Supplier choice	Supplier compliance with environmental criteria that take into account packaging requirements, energy consumption, fuel consumption and the degree of waste generation. Certification programs for suppliers containing green standards
Carrier choice	The use of special containers and transport for the transportation of dangerous and harmful substances, the correct choice of vehicle, optimization of routes, full and partial loading, multimodal transportation, the use of high-quality fuel and its savings thanks to highly qualified drivers
Choice of packaging	Use of eco-friendly and reusable packaging materials or those that are quickly recycled, use of reusable containers, labeling of packages with information on the chemical composition. Organization of the system of returns, collection, sorting and recycling of packages
Choice of an intermediary	Selection of optimally located logistics and distribution centers, warehouses, etc., which will ensure minimal transport costs and a high level of storage of goods. Reuse or repair of warehouse equipment, use of energy-saving equipment in work

Based on the main goals of ecologically oriented management of the enterprise, it is to obtain not only an ecological, but also an economic effect from the implementation of the principles of ecologistics. The implementation of these principles should ensure an increase in the reduction of the logistics cycle, the environmental quality of the product, an increase in the life cycle of the product, an increase in the use of production resources, a reduction in the volume of emissions and waste, a minimization of defective goods in warehouses and costs for their storage or transportation. The principles of ecologistics require a comprehensive approach to determine the goals of logistics management, they will allow companies to regulate commodity and material flows, gas and energy emissions, production and consumer waste, secondary material resources.

In order for companies to be able to implement the principles of green logistics in the activities of their enterprises, it is necessary, first of all, to improve their organizational structure for the coordination of all logistics functions, such as: production, supply and sales. In the future, companies need to create a new logistics function – an ecological one, which is implemented through the control and management of pollutant and waste flows, ensuring the maximum use of resource value, minimizing emissions and waste from production.

Due to the ever-increasing load on the environment and at the same time the desire to use the environment rationally and efficiently, while ensuring the future stability of generations, it is necessary to create conditions for its protection and protection.

Thus, the emphasis on the ecological orientation of enterprise logistics led to the emergence of ecologistics – a system of forming and managing logistics processes (transportation, storage, production movement, disposal) in order to limit the negative impact on the environment. To be truly effective in today's conditions, logistics activities must be coordinated with environmental strategies.

The use of waste reduces energy costs, reduces pollutant emissions and saves raw materials, in addition, firms thus improve their competitiveness and financial performance. In the near future, the assessment of suppliers will be carried out taking into account environmental factors. A significant element of savings resulting from the implementation of «green» supply chain solutions is a significant reduction in energy consumption. In dealing with household waste, it is necessary to use ecological principles, and treat secondary raw materials as a commodity necessary for the manufacture of new products.

6. Ecologistics in sustainable logistics flows of agricultural enterprises

We believe that the ecologistics of a modern agricultural enterprise is an innovative direction of logistics, which is related to the collection, transportation, processing, utilization or safe storage of waste generated during agricultural production with the aim of minimizing environmental pollution, reducing or reducing to a minimum the consumption of exhaustive natural resources and improving the efficiency of the use of logistics resources [37].

One type of environmentalism is defined as the circular economy, which includes logistics for reuse, recycling, processing and waste disposal in a feedback loop. In this regard, it should be noted that foreign and domestic scientists express different approaches to understanding the essence of the concept of «ecological logistics»: logistics of waste processing and utilization, logistics of secondary resources, logistics of recycling, logistics of reverse flows, reverse logistics, «green» logistics, resource saving logistics, recycling logistics, etc. At the same time, all these categories are close and not contradictory in meaning.

Foreign and domestic scientists distinguish 7 basic rules of conventional logistics, which include the necessary goods (product): of the required quality; in the required amount; in the necessary place; at the required time; the necessary consumer; with the required level of costs [40].

In our opinion, the basic rules of ecology, in addition to those related to conventional logistics, should be supplemented with the points of minimizing the volume of waste generation and accumulation and maximizing resource-efficient production due to the reuse of waste.

One of the important directions of environmentalism in sustainable supply chains is the solution of the problematic issue of handling waste generated during production, consumption, and transportation, which in the modern system of production processes is not sufficiently resolved at domestic enterprises. We believe that solving the problematic issue of handling agricultural waste, which is not sufficiently solved in the modern system of production processes at domestic enterprises, is one of the important areas of environmental science today. Taking into account the above, domestic enterprises need active implementation of environmentalism, especially in the field of development of waste-free production. For this purpose, there are a number of methods in world practice that can be implemented and applied. In general, closed-loop production systems have an advantage for the company not only from the point of view of reducing the impact of production activities on the environment, but also cost savings due to waste-free production.

According to the sources of origin, in accordance with the Waste Classifier DK 005-96, agricultural waste is divided into crop production waste and animal production waste, which in turn are divided depending on the stage of production or sale at which they were formed (Figure 17). All the specified types of agricultural waste are subject to further disposal or processing as secondary resources.

The ecologistics of an agricultural enterprise aims to perform functions related to the procurement of secondary raw materials, sorting, storage, temporary storage, secondary processing of waste within or outside the enterprise. If it is not possible to reuse and recycle waste directly within the enterprise, the environmental management of agricultural enterprises should perform the function of monitoring the needs of processing enterprises closest to the location in the relevant raw materials, as well as organize the transportation of these products in the most rational way.

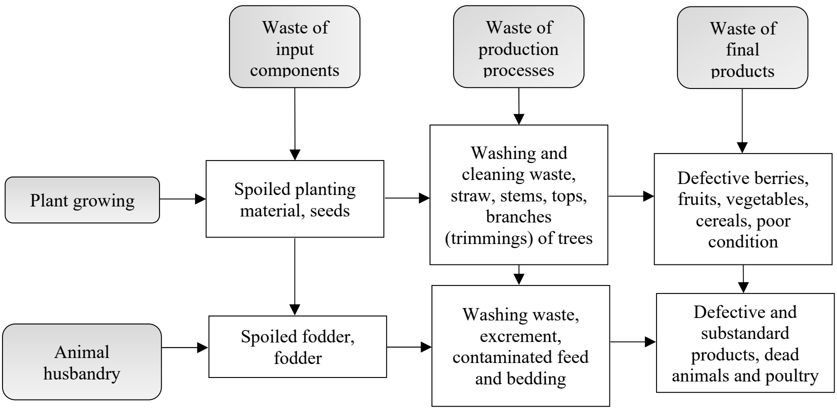

Figure 17. Agricultural waste by source

Source: created by the authors based on the State Classifier of Ukraine: Waste Classifier DK 005-96 [43]

Unfortunately, the cost of introducing ecological technologies into the production cycles of agricultural enterprises belongs to one-time investment costs, which not every enterprise can finance from its own sources. In addition, the payback of such investments is a rather long-term process and cannot be objectively assessed, since economic efficiency cannot be expressed in material and monetary form.

The assessment of investments in equipment and equipment for environmental pollution control and equipment for pollution prevention (mainly cleaning equipment), as well as in equipment and equipment related to environmentally cleaner technologies (complex technology) is presented in the Table 13.

Table data 13 indicate a significant improvement in investment in equipment and equipment for environmental pollution control and pollution prevention equipment for air and climate protection (0.1 million UAH in 2018 to 5.1 million UAH in 2020) and collection and liquidation of wastewater (1.7 million UAH in 2018 to 5.1 million UAH in 2020). A negative trend can be observed in terms of investment in equipment for the collection and liquidation of waste by agricultural producers (3.7 million UAH in 2018 to 0.3 million UAH in 2020). In 2020, investments in equipment and facilities related to environmentally cleaner technologies aimed at the collection and elimination of agricultural production waste amounted to 1.1 million UAH.

Table 13

The volume of investments in environmental equipment and equipment by agricultural enterprises of Ukraine in 2018-2020, UAH million

Years	Investments in equipment and pollution control equipment and pollution prevention equipment (mainly cleaning equipment)			Investments in equipment and facilities related to environmentally cleaner technologies (complex technology)	
	Protection of the surrounding air and climate	Wastewater collection and disposal	Collection and elimination of waste	Protection of the surrounding air and climate	Collection and elimination of waste
2018	0.1	1.7	3.7	0.1	-
2019	0.1	1.8	3.7	0.1	1.1
2020	5.1	5.1	0.3	0.1	1.1
Deviation, 2020-2018, +/-	5.0	3.3	-3.4	-	-

Source: calculated by the authors based on data from the State Statistics Service of Ukraine [19]

It should be noted that in 2020, the costs of agricultural producers for air and climate protection increased significantly – 13.2 million UAH, and during the analyzed period, the costs of waste collection and disposal are growing.

The study of foreign and domestic experience in the implementation of environmental measures gives grounds to generalize that the implementation of the ecological concept in the field of production and logistics becomes an impetus for: expanding the socio-economic space of interaction of internal and external effects; changes in the product portfolio to develop new eco-markets; expansion of the producer's relations with other producers («B2B» type relations) in related sectors of the economy; development of capitalization processes at enterprises thanks to the formation of long-term sources of value and increasing the investment attractiveness of eco-firms; formation of a system of «production-consumer» relations to overcome potential resistance of the public to innovations; development of innovative solutions in the corporate management system to avoid conflict of interests of various co-owners of equity capital (innovative eco-projects have higher risks, which affects the generation of net cash flows and their discount rate) [44].

Among the agricultural enterprises of the Vinnytsia region, the company «Myronivskyi Hliboprodukt» (hereinafter – MHP) implements the innovative principles of environmentalism on the basis of waste-free production on the largest scale. The enterprise is the largest producer of poultry products in Ukraine, also engaged in meat processing and growing of grain crops. Also, the priority goal of the MHP activity is the use of «green» energy (replacement of fossil fuels with alternative energy sources), environmental and energy security, organic agriculture, guided by the key principles of sustainable development. Each of the MHP enterprises has a full-time ecologist or a person who, according to the management's order, is responsible for environmental protection. Specialists responsible for environmental protection at the enterprise deal with issues of compliance with the requirements of environmental legislation; reducing the loss of energy and other resources, in particular, the volume of water use; reducing the impact of the holding's enterprises on the natural environment; prevention of emergency environmental situations and accidents that may lead to significant pollution of the natural environment [45].

The achievement of environmental goals at the enterprise is ensured thanks to the construction of two biogas complexes for waste disposal.

The biogas complex is a high-tech facility that transforms organic agricultural waste (biomass of plant origin, animal by-products and wastewater) into «green» energy according to the highest global environmental standards. The implementation of biogas projects allows MHP to effectively dispose of production waste, generate clean green energy, significantly reduce greenhouse gas emissions, and produce environmentally friendly organic fertilizers.

In 2019, the first stage of the «Biogas Ladyzhyn» complex with an energy capacity of 12 MW was put into operation. The facility is located in the village of Vasylivka, Tulchyn district, Vinnytsia region, and is part of the «Vinnytsia Poultry Farm» complex. At the same time, on an industrial scale, this energy will be enough to provide electricity for about 40% of the capacities of the agro-industrial cluster of the MHP. In addition, the biogas complex produces organic biofertilizers with a high content of nutrients necessary for plants [45].

The production indicators of the biogas complex of the MHP during 2018-2020 are shown in Figure 18.

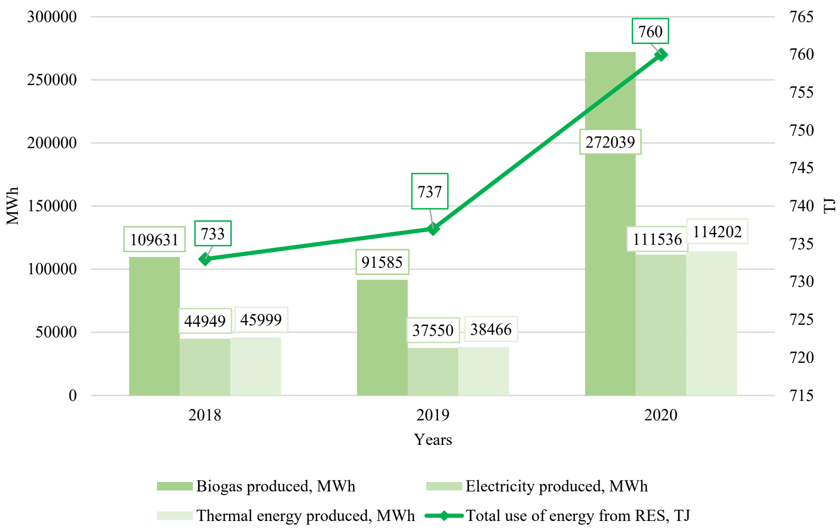

Figure 18. Production indicators of the MHP biogas complex in 2018-2020

Source: compiled by the author on the basis of the 2020 Sustainable Development Report of the MHP [45]

The consequences of implementing the principles of ecologistics to achieve waste-free production and reduce the environmental burden on the environment through biogas production at MHP complexes can be traced to the dynamics of changes in the main environmental indicators of MHP activity in Ukraine. Due to the implementation of waste-free biogas technologies, MHP ensures the reuse (recycling) of agricultural waste from its own activities, reduces energy consumption from non-renewable sources at the expense of energy from renewable sources, and also reduces emissions of greenhouse gases and carbon dioxide into the atmosphere (Table 14).

Table 14

The main environmental indicators of the implementation of waste-free technologies of agricultural production of MHP in Ukraine, 2018-2020

Indicators	**Years**			**Deviation 2020/2018, +/-**
	2018	**2019**	**2020**	
Emissions of greenhouse gases, tons CO_2	350391	328579	321428	-28963
Emissions from burning biomass, tons of CO_2, total including from burning biogas, tons of CO_2	96714 42261	88120 35308	150651 103342	53937 61081
Total fuel consumption, TJ including from renewable energy sources, TJ	8478 1232	8202 1141	8910 1950	432 718
Specific weight of renewable energy sources in the structure of total fuel consumption, %	15	14	22	7
Specific weight of renewable energy sources in the structure of total energy use, %	9	10	9	-
Share of reuse of agricultural waste, %	65.5	54.8	62.5	-3.0

Source: calculated by the author on the basis of the 2020 Sustainable Development Report of the MHP [45]

In 2020, direct emissions of greenhouse gases from the production activities of the MHP in Ukraine decreased by 2.18% due to energy-saving measures and a reduction in the consumption of gasoline and diesel fuel.

Total fuel consumption in 2020 fell by 2.98% compared to 2019 due to energy efficiency measures, increased biogas production and receipt of a green electricity tariff. The company does not use green electricity, but transfers it to the general electricity grid, which is in line with MHP's strategy to become a carbon neutral company.

As for waste management, organic agricultural waste generated as a result of the production activity of MHP is effectively transformed in biogas complexes and provides an opportunity to produce biogas and organic fertilizers (digestate), as well as significantly reduce greenhouse gas emissions. Biogas is transformed into thermal and electrical energy, and organic fertilizers are used on our own fields, which allows us to restore soil fertility and reduce the use of mineral fertilizers.

We believe that the main advantages of the implementation of ecological elements on agricultural enterprises can be combined into 3 effects: economic, ecological and social (Figure 19).

Based on the main goals set in the environmental policy developed by the enterprise, MHP embodies the main principles of environmentalism in its production activities, namely:

– rational use of enterprise resources and natural resources;

– maximum use of production waste as secondary raw materials;

– introduction of innovative waste-free technologies with the aim of reducing the ecological load on the environment;

– economically justified and environmentally safe transportation of waste;

– production of «green» energy, reduction in the use of fossil fuels, as a result of reducing import dependence on energy resources and reducing emissions of greenhouse gases and carbon dioxide into the atmosphere.

Thus, agricultural enterprises can introduce different approaches to waste ecologistics and the implementation of waste-free technologies, namely: purchase specialized equipment for safe waste transportation, optimize waste transportation routes from collection sites to waste processing, utilization and/or disposal sites, resulting in costs for waste transportation will be minimized; optimally dispose of waste that can be reused; promptly neutralize and bury waste that cannot be disposed of. With the spread of the use of ecologistics in agriculture, the processes of circular economy development are being intensified in Ukraine.

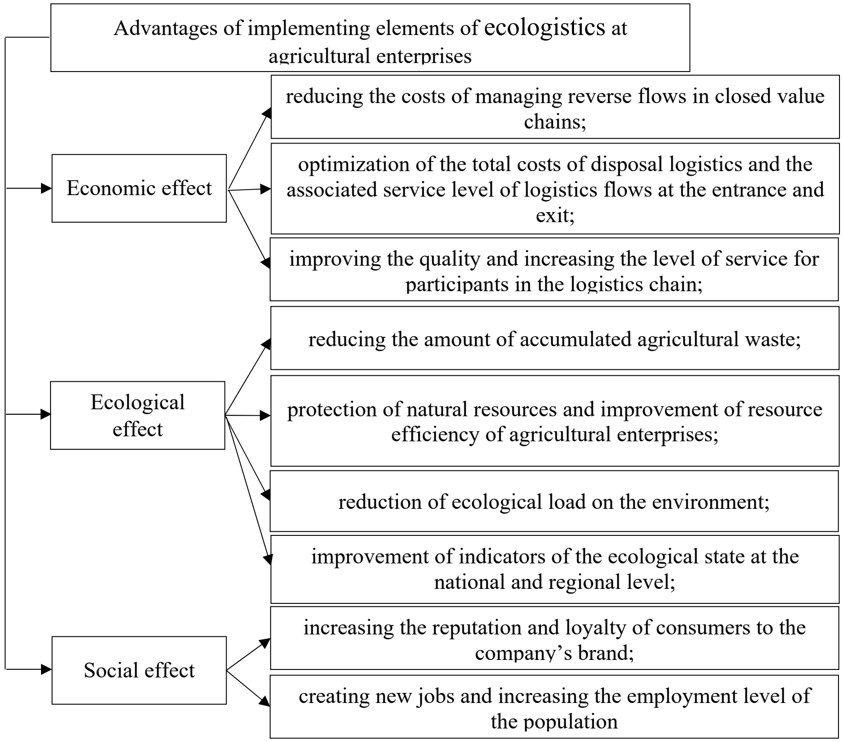

Figure 19. Advantages of implementing elements of ecologistics at agricultural enterprises

Source: authors' own development

The leader in Vinnytsia and the whole of Ukraine in the use of ecological principles in the implementation of waste-free production technologies is the MHP biogas complex, whose production indicators are growing every year. In the course of the research, the basic principles of environmentalism, which are embedded in the company's activities, were determined, which include the rational use of resources; maximum use of waste; introduction of innovative waste-free technologies; economically justified and environmentally safe transportation of waste; production of «green» energy. The application of the principles of ecologistics will help the enterprise to transform the logistics system, starting from the delivery of raw materials for the production of the final product and ending with the disposal and/or safe processing of waste, into an environmentally safe process. The conducted research made it possible to single out the main advantages of implementing the principles of ecologistics at agricultural enterprises to ensure waste-free technologies, which we propose to divide into 3 categories: ecological, economic and social effects.

7. Implementation of waste-free technologies as a result of the use of waste ecologistics processes at agricultural enterprises

An important factor in ensuring energy security and the transition to a circular economy model is the rational use of non-renewable fuel and energy resources or their replacement by renewable (alternative) energy sources. In addition to the use of solar, wind, geothermal, and hydropower, biotechnologies for the production of biofuels (biogas, bioethanol, biodiesel) occupy a prominent place in ensuring energy security.

The production of bioenergy, in particular, from waste, is called the process of waste-free production, which is the basis of the circular model of the economy. Waste-free technology is a method of manufacturing products that rationally and comprehensively uses raw materials and energy in the cycle of raw materials – production – consumption – secondary raw materials and any environmental impacts do not disrupt its normal functioning. In this definition, three main provisions are distinguished: the basis of waste-free production is the man-made cycle of substances consciously organized and regulated by man; necessarily rational use of all components of raw materials, the maximum possible use of the potential of energy resources (limited by the second law of thermodynamics); waste-free production, inevitably affecting the environment, does not disrupt its normal functioning and, therefore, does not harm it.

The concept of «waste-free technology» was formulated in the special «Declaration on low-waste and waste-free technology and the use of waste», which was adopted at the pan-European meeting on cooperation in the field of environmental protection in Geneva in 1979. According to the declaration, «waste-free technology is a practical application of knowledge. methods and means in order to ensure the most rational use of natural resources and energy within the framework of human needs and to protect the environment».

The European Economic Commission formulated the definition of the term «waste-free technology». Waste-free technology is the practical application of knowledge, methods and means to ensure the most rational use of natural resources and energy and environmental protection within the limits of human needs. Low-waste technology is understood as a method of manufacturing products in which part of the raw materials and materials become waste, but the harmful impact on the environment does not exceed sanitary standards. In a broad sense, the concept of «waste-free technology» covers the sphere of consumption. This technology assumes that manufactured products serve for a long time, can be easily restored (repaired), and at the end of their service life are returned to the anthropogenic resource cycle after appropriate processing or disposed of and buried as unutilized waste [47].

According to the researches of N. Boichuk and O. Mysiailo, the process of waste-free production has a cyclic nature, that is, waste from the production of one product is the raw material for the creation of the next. This process will continue until the waste is completely eliminated. The maximum use of raw material components indicates a comprehensive approach to this production. Thanks to this, the number of cycles of the production process will be reduced, which will make it possible to load the equipment more efficiently and reduce downtime, which will increase the number of manufactured products. Rational organization of the production process is the general principle of using waste-free technologies. The organization must ensure optimal use of resources and the search for modern ecologically oriented technologies that will ensure minimal impact on the environment. The need to transition to new waste-free technologies was caused by the understanding that existing production technologies are mostly open systems in which natural resources are irrationally used and significant volumes of waste are formed, which are sources of environmental pollution. In other words, modern society uses natural resources too wastefully, producing more and more consumer goods with a short life span using inefficient technologies, which leads to an extraordinary amount of waste [48].

In 1976, at the International Symposium on Low-Waste and Zero-Waste Technologies in Dresden, four main directions were identified in which waste-free technologies are developing:

1) development of various types of wasteless technological schemes and water circulation cycles;

2) creation and implementation of production waste processing systems and their consumption as secondary material resources;

3) development and implementation of fundamentally new processes for extracting substances with a reduced amount of waste;

4) creation of territorial production complexes (TPC) with a closed structure of material flows of raw materials and waste in the middle of the complex, including complex processing of raw materials [48].

In our opinion, to the previous four main areas of development of waste-free technologies, it is necessary to add one more important area – energy saving, energy efficiency and rational use of natural resources.

Waste-free production, like any other system, has its own characteristics and key principles (Table 15) [49].

All principles of waste-free production are important and unchanging. In order to comply with them, enterprises need to solve specific problems related to economic, organizational, psychological, technical and technological aspects.

During the implementation or improvement of technological processes of waste-free production at the enterprise, a number of general requirements must be observed:

– formation of production processes with a minimum number of technological stages, because waste is generated at each stage, as a result of which raw materials are lost;

– implementation of continuous processes that allow maximum use of raw materials and energy;

– increase in unit power of aggregates;

– increasing the intensity of production processes, as well as their optimization and automation;

– creation of energy-technological processes.

A clear example of waste-free production is the Swiss company Nestle SA, which reduces the amount of waste in all areas of business. The search for by-products is important and crucial here. The company works with local pig farms around the world to give chocolate waste a new purpose – as a source of energy. Spent, used chocolate is combined with organic agricultural waste, then added to an anaerobic digester and left for three weeks to decompose. The result is a combination of methane gas and nutrient-rich wastewater. Methane provides energy for pig farms, and wastewater with nutrients is used to irrigate local pastures [50].

Table 15

The essence of the principles of waste-free production

№	Principles	The essence of the principles
1	The principle of systematicity	It is based on the creation of waste-free production and takes into account the interrelationships and interdependencies of production, social and natural processes, where each individual production process is considered as an element of the dynamic system of the entire production, as well as at the highest level as an element of the ecological and economic system in general, which contains as material production, as well as other economic and economic activities of a person, the natural environment, as well as a person and his environment.
2	The principle of comprehensiveness of resource use	It provides for the maximum use of all components of raw materials and the potential of energy resources, taking into account that almost all raw materials are complex, and on average more than a third of their volume is associated elements that can be removed only in the case of complex processing.
3	The principle of cyclical material flows	It is one of the general ones, which can include closed water and gas return cycles. The level of cyclicality is a characteristic of the level of waste-free production. An effective way of forming cycles is the combination and cooperation of productions to ensure the reuse of final products and waste processing.
4	The principle of limiting the impact on the environment	Implementation of the principle is possible only in the presence of effective environmental monitoring, effective mechanisms of environmental policy, achievements of NTP, etc. The level of minimization of the impact on the recipients of the environment is at the same time a characteristic of the approach of the technology to the global standards of production quality, which contributes to the spread of the technology and final products to the markets of developed countries.
5	The principle of rational organization of production	It is characterized by the reasonable use of all components of raw materials, the maximum reduction of energy, material and labor intensity of production and the search for new ecologically based raw material and energy technologies, which is largely related to the reduction of the negative impact on the environment and causing damage to it, taking into account the adjacent fields of folk economy The ultimate goal is to optimize production simultaneously in terms of energy-technological, economic and environmental parameters. The only way to achieve this goal is to develop new and improve existing technological processes and productions.

Source: summarized by the authors based on [49]

Another successful example is the Dutch-British company Unilever, which leads the list of the best companies with zero waste. Unilever achieved its goal of «zero waste to landfill» in 2016, six years ahead of schedule, and has supported the concept ever since. To do this in a company with 242 factories in 67 countries producing a wide range of products required a lot of innovation. Some of their unique efforts include turning tea waste into textile dyes and reusing the sludge to feed earthworms. According to Unilever, the implementation of environmentally friendly initiatives has created numerous jobs and helped the company save more than 225 million US dollars. However, it does not plan to stop there and has pledged to use only 100% recyclable, reusable or compostable packaging by 2025 [51].

Microsoft has announced that it will switch to waste-free production by 2030. General Manager of Microsoft for Energy and Environmental Sustainability Br. Janus says the company aims to increase the refurbability of devices and balance that with other aspects of manufacturing, such as safety, durability and reliability [52].. For this purpose, the company aims to create appropriate special «circulation centers» and process waste at its own expense.

A vivid example of domestic companies that adopted the EU experience in waste-free production is the T. B. Fruit group of companies, which assures that it is completely dependent on natural resources and the sustainability of ecosystems. T. B. Fruit is one of the first in Ukraine to introduce waste-free, environmentally friendly production. The company collects raw materials exclusively in ecologically clean areas and processes them into direct pressed juice (NFC), as well as making concentrated juice. During juice production, all aromatic substances that evaporate into the air condense and obtain natural flavors, and pectin is made from the cake that remains after squeezing. Fruit waste that was not used for pectin production, as well as wood chips, are used as biofuel for the production facilities, because the company has not used natural gas since 2007, but only its own biofuel from the harvest. T. B. Fruit fully utilizes all processing products, resulting in no waste that would pollute the environment. In addition, the company also conducts an active environmental policy regarding the effective use of energy resources and individual reduction of waste [53].

Another example is «VIVAD 09» – is a powerful wood processing enterprise located in the village of Romaniv in the Zhytomyr region.

The company`s production process involves the processing of all raw materials, including those that could be considered waste. Waste from the production of lamellas and parquet is processed into solid fuel – fuel briquettes. This makes it possible to make the company's production process completely waste-free. Rationality and capacity analysis helped the company reach zero waste, due to which it does not spend additional funds on disposal, increases the product range, and receives additional profit [54].

The concept of waste-free technologies in agriculture is characterized by the following basic provisions:

– introduction of closed production systems that are as close as possible to natural ecological systems;

– resource conservation (effective and most rational use of raw materials and materials at all stages of production);

– waste generated as a result of agricultural production should not have a negative impact on the natural environment.

In order to increase the amount of investment in technological innovations of waste-free production, which will contribute to the development of the circular economy model, it is necessary to diagnose the possibility and readiness of the enterprise to implement waste-free technologies at enterprises (Figure 20).

Today, the maximally complete use of agricultural waste is an important scientific, technical, economic, ecological, social problem, the solution of which largely depends on the efficiency and balance of agriculture and the agricultural industry as a whole. It should be noted that specific agricultural waste is characterized by numerous specific features. This is almost the main difficulty of managing and planning the process of involving agricultural waste in business practice. It is important to give this process a general orientation, without excluding, of course, the adoption of specific measures at different levels of management [55].

In general, the data section (Table 16) during 2010-2020 shows positive dynamics of electricity production from renewable sources (wind, solar, hydroelectric power plants, biofuel and waste) in Ukraine.

Thus, most energy in Ukraine in 2010-2020 was produced from nuclear energy, coal and peat, and natural gas. We can also trace the trend towards a gradual increase in energy production from biofuels and waste by 2,980 thsd toe per year in 2020 compared to 2010. The share of energy production

Algorithm for monitoring the possibility and readiness of an agricultural enterprise to implement waste-free technologies

- *Stage 1.* Analysis of existing technologies used at the enterprise.
- *Stage 2.* Comparison of existing technologies with world-class advanced technologies.
- *Stage 3.* Identification of «critical points» in the technologies used at the enterprise.
- *Stage 4.* Assessment of the company's capabilities to implement more modern waste-free or low-waste technologies.
- *Stage 5.* Search for sources of financing for the introduction of more modern waste-free or low-waste technologies.
- *Stage 6.* Conclusion of contracts or development of documentation for the introduction of waste-free technologies at the enterprise.
- *Stage 7.* Organizational work and implementation control.

Figure 20. Algorithm for monitoring the possibility and readiness of an agricultural enterprise to implement waste-free technologies

Source: authors' own development

from biofuels and waste in 2020 reached 7.8% (1.85% in 2010), although the goal set by Ukraine as part of the implementation of the European Green Course is to increase the share of energy production from biofuels and waste to 8.1% by 2020 – was not achieved.

Growing concerns about energy security and climate change caused by greenhouse gas emissions from fossil fuel consumption have prompted many researchers to participate in the development of renewable energy sources. Examples of the most promising waste-free technologies at agricultural enterprises are biofuel production technologies from biomass: biodiesel, biogas, and bioethanol.

Biomass is considered one of the key renewable energy resources of the future, as it provides 14% of primary energy consumption. Biomass consumption is growing rapidly. For example, Sweden and Austria provide 15% of primary energy needs from biomass, and the USA – 4%. The calorific value of dry biomass is about 14 MJ/kg [57].

Table 16

Dynamics of the level of production of various types of energy in Ukraine in 2010-2020, thsd toe

A type of energy	Years							Deviation, 2020/2010
	2010	2015	2016	2017	2018	2019	2020	
Coal and peat	33716	17423	22869	13696	14087	14446	12753	-20963
Crude oil	3590	2618	2304	2208	2341	2478	2476	-1114
Oil products	-	-	-	-	-	-	-	-
Natural gas	15426	14814	15175	15472	16487	16318	15856	430
Atomic energy	23387	22985	21244	22449	22145	21771	19994	-3393
Hydroelectric power	1131	464	660	769	897	560	650	-481
Wind, solar energy	4	134	124	149	197	426	794	790
Biofuel and waste	1458	2606	3348	3575	3726	3786	4438	2980
Electricity	-	-	-	-	-	-	-	-
Heat energy	-	571	599	546	534	667	56	-

Source: created by the authors based on data from the State Statistics Service of Ukraine [19]

It is well known that the output of biogas depends on the composition of the substrate, its bioavailability and production technology. It is worth considering the potential of biogas output from each individual substrate, namely, what amount of biogas can be obtained with practically infinite fermentation of the substrate under stable conditions. Of course, in real conditions, this figure is very rarely reached (or practically not reached) due to the economic impracticality of such a long process, but the indicator at the level of 60-95% is achievable and economically justified.

In Figure 21 shows the volumes of biogas production using various raw materials. When choosing biogas plants, it should be borne 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.

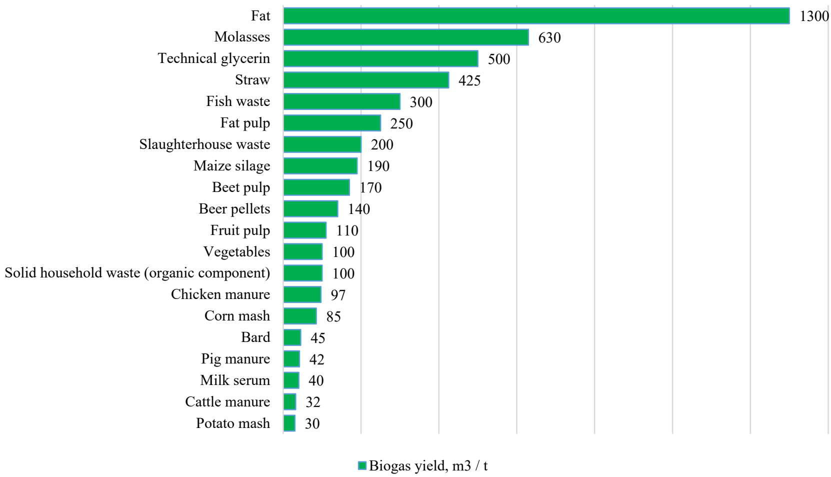

Figure 21. Biogas yield from 1 ton of substrate

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

Therefore, Ukraine has a well-developed agriculture, the waste of 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 the work of livestock and crop farms will allow obtaining more than 10 billion m^3 of gas.

In view of the above, it can be concluded that the existing potential of biogas production from organic agricultural waste in Ukraine and the significant advantages of using biogas technologies for energy generation create favorable conditions for the development of the domestic agrobiogas sector. According to the data of the Bioenergy Association of Ukraine, the average indicator of electricity production from biogas in 2020 was about 36,0 million kWh. Savings in capital costs when using biogas plants in enterprises is 30-40%.

Equating the selling price of biogas to the price of natural gas (9.9 thsd UAH per 1000 m^3), the gross profit from the production of biogas for agricultural formations of Ukraine can reach from 5.08 to 24.86 million UAH depending on the type of raw material. For the enterprise, the advantages of implementing a biogas plant are cost savings due to the production of electricity and thermal energy from its own raw materials, a reduction in dependence on external energy carriers, and 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 thermal energy due to cooling of engines after burning biogas for electricity production. However, the economic benefits of using 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 [47].

Ukraine also has significant biomass potential available for energy production. The assessment of the energy potential of biomass in Ukraine for 2019 is presented in the table 17.

Biogas technology is a relatively simple, waste-free, energy-saving, economically viable and environmentally friendly technology. The annual technically achievable energy potential of biogas is 1,22 million toe; of them, biogas from waste and by-products (APK) – 0,99 million toe; from solid waste landfills – 0,14 million toe; from waste water – 0,09 million toe. The total energy potential of biogas is the largest in urbanized regions and regions with intensive livestock and poultry farming – in the Kyiv, Donetsk, Dnipropetrovsk, Cherkasy, and Vinnytsia regions and ranges from 0,116 to 0,241 million toe/year [58].

Thus, the production of biogas from agricultural waste, especially livestock waste, can increase the efficiency of the enterprise. For example, energy from biogas, unlike renewable sources of energy – the sun, wind, oceans, etc., is continuous and does not depend on weather conditions, time of day or other natural and climatic factors. Biogas is a reliable source of energy and can be produced both from renewable raw materials (corn silage, cereals, green mass) and from by-products and waste of organic origin.

Modern biogas plants are increasingly equipped with modules for biogas purification. As a result of several technological operations, the methane content increases to 90%, side gases are removed. After further purification of biogas, bioethanol is produced, which in terms of its properties is as close as possible to natural gas and can be supplied to the general gas distribution network without any obstacles.

Table 17

Assessment of the energy potential of biomass in Ukraine in 2020

Type of biomass	Theoretical potential, million tons	Potential available for energy (economic)	
		Part of the theory. potential, %	million toe
Straw of grain crops	37.5	30	3.84
Rapeseed straw	5.9	40	0.81
By-products (hereinafter – PP) of corn (stalks, rods)	46.6	40	3.57
PP sunflower (stems, baskets)	26.0	40	1.66
Secondary residues of agriculture (sunflower husks)	2.6	100	1.08
Wood biomass (fuel wood, sawing residues, woodworking waste)	7.4	95	1.73
Wood biomass (dry, wood from protective forest strips, PUPAP waste*)	8.8	45	1.02
Biodiesel (from rapeseed)	-	-	0.46
Bioethanol (from corn and sugar beet)	-	-	0.79
Biogas from waste and PP of agricultural industry	2.8 billion m^3 of CH4	42	0.99
Biogas from solid waste landfills	0.6 billion m^3 of CH4	29	0.14
Biogas from wastewater (industrial and municipal)	0.4 billion m^3 of CH4	28	0.09
Energetic plants:			
- willow, poplar, miscanthus, on 1 million ha of unused agricultural land	11.5	100	4.88
- corn (for biogas), on 1 million hectares of unused agricultural land	3.0 billion m^3 of CH4	100	2.57
In total	-	-	23.63

* PUPAP – pruning and uprooting of perennial agricultural plantations

Source: created by the authors based on data from the Bioenergy Association of Ukraine [58]

During the cooling of the biogas plant, heat is generated in the form of hot water, which is used for heating premises, greenhouses, warehouses, etc. From 1 m^3 of biogas in a combined heat and power plant, 2.8 kW of thermal energy can be produced. It is also possible to produce electricity from biogas for own consumption or sale at a green tariff to the state. About 2.4 kW of electricity can be produced from 1 m^3 of biogas.

During the production of biogas, organic fertilizer is formed – digestate. This substance is close in chemical composition to compost, therefore, it can be used as an additional fertilizer to increase soil fertility. Digestate improves the condition of agricultural crops by providing additional nutrients and helping to maintain the necessary soil moisture. If mineral fertilizers are assimilated by only 35-50%, then biofertilizers – by almost 99% [59].

The production of biogas makes it possible to prevent methane emissions into the atmosphere, reduce the amount of chemical fertilizers used, and eliminate the risk of groundwater pollution. The production of energy from biogas does not require the use of fossil sources, and additional volumes of carbon dioxide do not enter the atmosphere. That is, the use of biogas plants that operate on agricultural waste is not only the provision of energy security and autonomy of the enterprise, but also one of the factors of the country's transition to a low-carbon economy.

The rational and complex use of raw and energy resources allows for the introduction of inter-branch cooperation, in particular within the framework of the territorial production complex, with the aim of using waste by some enterprises of others. The main task is to find opportunities for the use of unfinished products in other industries or sectors of the national economy, which could build their activities on them as secondary material resources.

In the Vinnytsia region, there are two powerful enterprises for the production of biogas from livestock waste and biogas from plant waste LLC «Vinnytska ptakhofabryka» and LLC «Iuzefo-Mykolaivska biohazova kompaniia». The region is not only a leader in the production of gross agricultural products, but can also become one of the leaders in the implementation of waste-free technologies that provide a full cycle of the circular economy.

Also, a bright example of the effective use of recycled waste from own production is a young agricultural enterprise in Vinnytsia – LLC «Organik-D», which works according to the principle of waste-free production, while using its own biogas plant.

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

– biogas output (1200 m^3/day);

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

– organic fertilizer digestate (60 tons/day), with which he enriches his own agricultural land [18].

The introduction of biogas stations at agricultural enterprises will allow to establish an ecologically clean, 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, reducing costs and the cost of manufactured products due to the provision of energy resources and organic fertilizers for the main production of enterprises. When using a biogas plant, the actual energy consumption is 20% of the received energy. In the case of using biogas for the simultaneous production of electricity and thermal energy (cogeneration), 30-40% of the energy is converted into electrical energy, 40-50% into thermal energy, the rest is directed to its own needs.

Therefore, agriculture, in particular animal husbandry, can make an important contribution to the fight against climate change by transitioning to a circular economy, sustainable production through the implementation of environmentally safe resource-saving technologies for processing crop residues and animal manure into biofuel. Utilization of agricultural waste, namely livestock waste by processing it into biogas, is an important aspect not only of the environmental friendliness of this process, but also contains an energy component – ensuring energy security, i.e. the use of one's own renewable raw material base and rejection of fossil energy carriers or imports, diversification of energy supply. However, the economic benefits of using 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.

Conclusions

Today, agricultural waste is, on the one hand, a source of environmental pollution, and on the other hand, this type of waste is converted into energy and fuel in an environmentally safe way, thus ensuring energy independence. The real volumes of agricultural waste in Ukraine, more than

90% of which can be used in recycling processes, are many times higher than the figures given by official statistics. In Ukraine, there is a need to increase the efficiency of waste management of agricultural enterprises in accordance with European and global trends. A promising direction is the use of agricultural waste for energy purposes – the production of biofuel.

The circular economy has a huge potential for solving environmental and economic problems. The transition to this concept will contribute to reducing the use of energy resources of the earth, reducing the cost of production. The creation of «green» markets and new business models will provide new jobs. It is this concept that is a universal alternative to the linear economy, which will make it possible to achieve a sustainable state in all spheres of human life and preserve life on our planet.

Thus, agricultural enterprises can introduce different approaches to ecologistics of waste and the implementation of waste-free technologies, namely: purchase specialized equipment for safe waste transportation, optimize waste transportation routes from collection sites to waste processing, utilization and/or disposal sites, resulting in costs for waste transportation will be minimized; optimally dispose of waste that can be reused; promptly neutralize and bury waste that cannot be disposed of. With the spread of the use of ecologistics in agriculture, the processes of circular economy development are being intensified in Ukraine.

The leader in Vinnytsia and the whole of Ukraine in the use of ecological principles in the implementation of waste-free production technologies is the MHP biogas complex, whose production indicators are growing every year. In the course of the research, the basic principles of ecologistics, which are embedded in the company's activities, were determined, which include the rational use of resources; maximum use of waste; introduction of innovative waste-free technologies; economically justified and environmentally safe transportation of waste; production of «green» energy.

The application of the principles of ecologistics will help the enterprise to transform the logistics system, starting from the delivery of raw materials for the production of the final product and ending with the disposal and/or safe processing of waste, into an environmentally safe process. The conducted research made it possible to single out the main advantages of implementing the principles of ecologistics at agricultural enterprises to ensure waste-free technologies, which we propose to divide into 3 categories: ecological, economic and social effects.

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Iespiests tipogrāfijā SIA “Izdevniecība “Baltija Publishing”
Parakstīts iespiešanai: 2023. gada 27. februāris
Tirāža 300 eks.