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Prospects for the introduction of a green economy in the agricultural sector of Ukraine for the next 10 years

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Abstract. The relevance of the study is due to the deterioration of the environment and the low level of application of green technologies in the agricultural sector of Ukraine. The aim was to outline the current problems for farmers in the use of green farming methods and to find solutions. The study assessed the level of use of certain green technologies in agricultural production in Ukraine. The main results obtained in this work are: determining Ukraine's place in the Green Future Index ranking in various areas during 2021-2023 and comparing it with Iceland, Finland, and Norway;

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identifying areas of green technologies that need to be developed in Ukraine during martial law and after the war (precision and organic farming, the introduction of biotechnology to create genetically modified organisms and the transition to alternative energy sources). The study of the dependence of farmers' propensity to use green technologies on the size of farming confirms its undeniable presence. The analysis of foreign experience in precision agriculture allowed formulating recommendations for foreign companies entering the Ukrainian market to promote the use of precision agriculture in Ukraine. The findings on the growing electricity shortage helped to justify the further use of alternative energy sources in the context of the conflict. A study of the negative impact of the hostilities on Ukrainian land allowed classifying such types of impact and developing measures to restore the soil. The assessment of the use of technologies in agriculture helped to identify areas for the introduction of a green economy in the agricultural sector in Ukraine, which will help to increase agricultural yields without harming the environment and increase its competitiveness. The results and conclusions have practical implications for the Government in developing agricultural policy and for farmers in managing their farms

Keywords: precision agriculture; agricultural products; innovative technologies; renewable energy; welfare; yield

INTRODUCTION

Over the past 20 years, climate change has been a fundamental global challenge for all of humanity. Every year, environmental damage and global warming become more and more threatening to human health. Climate change affects food security and the survival of humanity. The European course of economic development chosen by Ukraine envisages the approximation of economic development to the principles of a green economy, which means innovative and strategic ways of economic development that take into account the improvement of environmental and social effects that ensure sustainable economic growth. Ukraine's agricultural sector is already actively using green technologies. However, the wartime events, which have become particularly acute since the beginning of the full-scale invasion, have significantly complicated and impeded the improvement of all areas of the country's development. The agricultural sector is particularly affected by the hostilities in the eastern, southern and northern parts of Ukraine, and the agricultural sector as a whole is experiencing financial difficulties, a shortage of workers and other problems. In this regard, it is important to analyse the state of application of green technologies in agriculture and develop proposals for the introduction of a green economy in wartime, which would help to increase the efficiency of agriculture as a leading industry in Ukraine.

It is important to study theoretical and methodological approaches to defining the essence of the concept of green economy in order to substantiate the essence of certain categories and concepts used in the development of measures aimed at identifying the main factors that can bring agriculture closer to the use of green technologies. The study of the essence of the green economy was paid attention to by T. Zinchuk *et al*. (2022), who emphasized that the main idea of the transformation of the national economy after the war is to modernize the economy and implement the principles of its recovery. The study of the green economy in the context of globalization has been paid due attention to by L. Horbach *et al*. (2024) and O. Petrenko (2023), who argue that green technologies that reduce carbon emissions are important for income and employment growth, as well as for increasing public and private investment. In addition, O. Petrenko emphasizes that the government should make decisions that support the improvement of environmental friendliness in the agricultural sector, in particular: support the exchange of knowledge between representatives of different agricultural enterprises.

Due to military events and long-term physical and chemical impact on agricultural land, it is depleted and quite polluted, which necessitates a number of measures to improve soil quality. Research in this area was carried out by I. Smolii and N. Dikhtyarenko (2023), who highlighted that the implementation of the "greening" of the agricultural economy requires the elimination of environmental problems: degradation of agricultural land, pollution of species, and carbon emissions into the atmosphere. However, the studies of the above-mentioned scholars hardly highlight the principles that should be taken as a basis for the application of green technologies in Ukraine. Reducing carbon emissions is one of the ways to achieve a green economy in agriculture as part of the global community's efforts to mitigate climate change (Matyushenko *et al.*, 2022). However, the relationship between innovations in green technologies and carbon emissions' reduction has not been sufficiently studied. Research in this area was conducted by F. Dong *et al.* (2022), who identified the countries (Luxembourg, Norway, and Switzerland) with the lowest emissions and emphasized that innovations in green technologies directly affect carbon efficiency. Conducting research in this area, P.S. Michael (2022) examined available technologies to reduce carbon and pollution emissions and prevent biodiversity loss, and pointed to the specific role of technology in promoting sustainable agriculture to improve rural livelihoods.

The introduction of digital technologies in agriculture spurs increased production, yet it is crucial to

consider the unique natural and other characteristics of each region in Ukraine. This perspective is supported by M. Hong *et al.* (2023), who examined the relationship between the digital economy and green agricultural development, analysing the temporal and spatial effects of the digital economy, along with heterogeneity across dimensions and regions. The development of various economic sectors should be grounded in the principle of social responsibility to society. The agricultural sector faces numerous challenges that threaten its long-term sustainability, such as environmental degradation, climate change, and social and economic inequality (Rumiantseva *et al.,* 2022). Addressing these challenges can be guided by a green economy and sustainable development perspective, which offers a framework for fostering agricultural development while preserving natural resources and enhancing social equity in the region. This highlights the significance of environmentally friendly and socially responsible agricultural practices, the necessity for sustainable resource management, and the advancement of renewable energy sources. Research by M. Gavrilović *et al.* (2023) demonstrated that adhering to the principles of a green economy and sustainable development can ensure agriculture remains a vital and sustainable source of economic growth and development for future generations. K. Mehta *et al.* (2022) also explored this issue, examining the economic, social, and environmental characteristics of the sector and identifying significant challenges and opportunities for the green economy in the country.

Despite significant scientific contributions to the implementation of a green economy in the agricultural sector, the methods that can be employed in Ukraine's agricultural sector to enhance the environmental friendliness of crops and digitalize production need further exploration. The study aimed to assess the current state of green technology implementation in Ukraine's agricultural sector and to propose suggestions for its expansion. The primary objectives were to identify the benefits of a green economy for the agricultural sector and determine which areas should be developed for implementation in agriculture.

MATERIALS AND METHODS

The research on this issue was carried out based on the data of the agricultural sector of Ukraine for the period 2021-2023. The prospects for the introduction of green technologies in agricultural production were assessed using the following methods:

- a comprehensive approach to studying the challenges faced by agricultural enterprises in growing crops and cultivating land in Ukraine during the war;
- the average percentage of precision farming technologies used by certain categories of farmers;
- a comparison of the indicators of the agricultural sector of Ukraine with similar data from other countries;
- a random method for determining the estimated timing of activities;
- a graphical method of displaying data.

The Green Future Index (2023) for Ukraine is ranked among 76 countries and compared to Iceland, Finland, and Norway based on data from the MIT Technology Review's Special Content Unit. This overall ranking assesses the performance of the economies under study in the following five pillars: carbon emissions, energy transition, green society, clean innovation, and climate policy. Information on the total area of land under organic farming was obtained from the web portal Our World in Data (Organic agricultural area…, n.d.), which contains an analysis of data on poverty, disease, climate change, war, and other indicators. Determining the average percentage of precision farming technologies for different categories of farmers (1 – cultivating up to 1,000 ha; 2 – from 1 to 3 thousand ha; 3 – from 3 thousand to 10 thousand ha; 4-10 thousand ha and more) allowed determining which category of farmers has a more positive attitude towards precision farming.

To analyse the legal framework regulating the cultivation of genetically modified organisms (GMOs), the Law of Ukraine No. 3339-IX "On State Regulation of Genetic Engineering Activities and State Control over Placing Genetically Modified Organisms and Products on the Market" (2023) is taken into account. Using a comprehensive approach, the article investigates and identifies problematic issues related to the application of organic and precision agriculture in the agricultural sector of Ukraine in the pre-war period and during the war.

The data on the structure of energy sources used in Ukraine was obtained from the German online platform Statista (n.d.), which specializes in collecting and visualizing data from around the world. Information on damage to agricultural land caused by physical and chemical damage to the soil as a result of hostilities was analysed on the basis of data from the official resource of the Ministry of Environmental Protection and Natural Resources of Ukraine (n.d.). The graphical method is used to depict the presentation of the principles of the green economy, demonstrate Ukraine's place in the Green Future Index (2023) ranking in various areas during 2021-2023, and the structure of electricity production in Ukraine in 2023. To determine the approximate timeframe for the implementation of certain areas of the green economy in agriculture for the next 10 years, the time periods up to 2034 were randomly selected.

RESULTS

The essence and role of the green economy. The term "green economy" was initially introduced by scientists specializing in economics and ecology (Anderson, 2024). It gained international prominence in 2008 during the global financial crisis when the United Nations Environment Programme (2021) highlighted the

importance of incorporating environmental initiatives into economic recovery plans worldwide. The Global Green New Deal report (2009) outlined economic recovery policies that prioritize global sustainability (Anderson, 2024). Despite this, the global economy remains marked by humanity's excessive consumption, which harms nature and contributes to climate change. In 2015, UN member states adopted the Sustainable Development Goals for 2030, aiming to reduce environmental impacts globally and implement significant economic and institutional changes (Partners for Inclusive Green Economies, 2019).

The green economy concept emphasizes reducing carbon emissions, increasing energy and resource efficiency, and preventing biodiversity loss. The Partners for Inclusive Green Economies (2019) document, presented at the UN High-level Forum on Sustainable Development, outlines five fundamental principles of a green economy. These principles explain how economic growth can be aligned with environmental sustainability and social inclusion (Fig. 1).

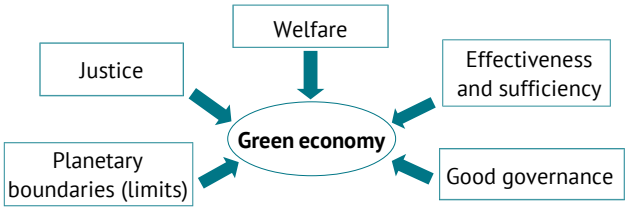

Figure 1. *Five principles of a green economy*
Source: *compiled by the authors*

Figure 1 illustrates that the fundamental principles of a green economy involve balancing the well-being of the population with the preservation of a clean environment. Specifically, the principle of well-being emphasizes the importance of providing open access to basic resources and education, fostering an environment where businesses can thrive. The principle of equity focuses on ensuring the fair distribution of resources and opportunities across all generations. The principle of planetary boundaries aims to limit the impact of human activities on the planet's nature, as exceeding these limits compromises the ability to regulate the environment. Advocating for sustainable production and consumption, the principle of efficiency and sufficiency emphasizes the development of low-carbon, resource-efficient, diverse, and circular economic models. This principle promotes responsible consumption and the fulfilment of basic needs. Additionally, the principle of good (effective and accountable) governance is crucial for the success of a green economy. It requires business entities to base decisions on a blend of scientific research, economic analysis, and practical knowledge, and to create a financial system that ensures economic growth does not compromise environmental health (Partners for Inclusive Green Economies, 2019).

The principles described above sufficiently reveal the essence of the green economy. Agriculture plays a key role in ensuring the well-being of humanity, as it is directly linked to food production and environmental impact. Most of the natural resources needed to produce products are extracted from the earth and often used only once and then discarded. This process is called "take – make – waste", which means the irrational use of natural resources that harms the environment. Since 1970, natural resource extraction has increased 3-fold, and according to scientists, it is expected to grow by 70% by 2050. Given the projected increase in global population to 9 billion people by 2050 (United Nations Environment Programme, 2021), the need to provide humanity with food, fuel and other resources that should be produced with minimal environmental impact will become more acute in the future. The most financially costly Sustainable Development Goals in 2022 were dominated by those related to the implementation of environmental projects, namely Goal 7 "Affordable and Clean Energy", Goal 11 "Sustainable Cities and Communities" and Goal 13 "Climate Change Mitigation", which accounted for 48% of the funding for all goals (Sustainable Bonds Insight, 2023).

A comparative ranking of 76 countries and territories in terms of their ability to develop a sustainable, low-carbon future is presented in The Green Future Index, 2023. The index measures the extent to which a country's economy is transitioning to a clean energy, industry, agriculture, and society through investments in renewable energy, innovation and the green economy. According to The Green Future Index (2023), the countries that are most prepared for a low-carbon future are Iceland (6.69), Finland (6.68) and Norway (6.37). Ukraine ranked 47th in this ranking in 2023 with a score of 4.38 (Fig. 2).

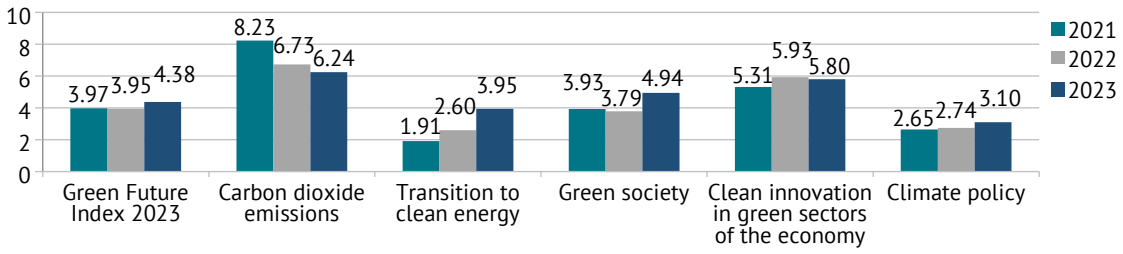

Figure 2. *Ukraine's ranking in the Green Future Index in different areas in 2021-2023*
Source: *compiled by the authors based on The Green Future Index (2023)*

The data in Fig. 2 shows that Ukraine has risen in the ranking among 76 countries in almost all indicators over the past three years. A particularly positive trend is observed in the Transition to clean energy and Green Society indicators. However, Ukraine needs to make significant efforts to reduce carbon dioxide emissions and reduce its environmental impact (The Green Future Index, 2023).

Overall, Ukraine is making some progress in implementing green technologies, but additional efforts are needed in all sectors of the economy. One of the sectors that provides food for the population and is a key player in Ukraine's trade and economic relations on the global market is agricultural production. Ukraine has an enormous potential for the development of agricultural production, given its high land fertility and favourable climate for growing many crops that are essential for the food supply of the world's population. At the same time, the slow development of agricultural technologies, inefficient use of agricultural land, increased use of pesticides, which affects the quality and environmental friendliness of products and land fertility, as well as military operations in Ukraine that lead to air and soil pollution, increase the relevance of new green technologies that will help the agricultural sector reach a new level of development.

Prospects for expanding the use of precision (accurate) farming. Global trends in the use of green technologies in the agricultural sector focus on the application of the latest technologies that can increase productivity and reduce the environmental impact of agriculture. Such technologies include:

- precision (accurate) agriculture, which is based on observations, measurements and timely response to changes in crop cultivation;
- the use of organic farming (compost for soil fertilization, green fertilizers, biological pest control, crop rotation technologies (alternating crop species or varieties on the same sown area over a certain period of time), which lead to increased soil fertility);
- introduction of biotechnology to create genetically modified organisms that do not require the use of large amounts of fertilizers and pesticides;
- switching to alternative energy sources (wind, solar, water, geothermal and other types of energy).

Precision farming means that plants receive exactly what they need for growth, development, and yield (Lopushnyak *et al*., 2022). These needs are determined with high precision thanks to the latest technologies, including: electronic positioning and speed (GPS), sensor technology, computer information technology and robotics. Precision farming technologies have already penetrated agriculture in Ukraine to a large extent, but further implementation is needed to increase their technological efficiency. For example, the level of precision farming application varies depending on the category of agricultural producers: small farmers are the least common, while large agricultural holdings are quite developed, as some of them have their own structural units, such as innovation departments. The results reflect the current state of application of precision farming technologies by different categories of farmers: small farmers with less than 1,000 ha and 1,000-3,000 ha, medium farmers with 3-10,000 ha, and large farmers with more than 10,000 ha of land per region (Table 1).

Table 1. *Information on the use of precision farming technologies by different categories of farmers*

Categories of farmers	Use of electronic field maps, %	Land digitization, %	Autopilots, GPS trackers, %	Satellite imagery/NDVI	Own weather stations and soil moisture sensors, %	Access to finance
up to 1,000 ha	15	90	-	1/10	< 20	complicated
1-3 thousand ha	47	90	> 50	38	up to 50	complicated
3-10 thousand ha	67	91	8 out of 10	> 50	> 50	more affordable
10+ thousand ha	95	93	90	> 80	> 75	more affordable

Source: *compiled by the authors based on Netherlands Enterprise Agency (2021)*

Table 1 shows that farmers with up to 1,000 ha of land do not consider using integrated farm management systems, as the implementation of such a system requires both a financial component and a pre-formed information base for their own company. Owners of up to 1,000 ha and 1-3 thousand ha face problems with the integrated and consistent use of precision farming technologies. The category of farmers with 10,000 ha or more implement technologies centrally. The process of testing and scaling for all innovations takes up to 3 years, such as Kernel. This category of farmers uses satellite imagery, drones (both independently and with the help of relevant specialized companies), implementation of FieldView and Cropio management systems (Netherlands Enterprise Agency, 2021).

In conformity with the results of the farmers' survey, the average level of precision farming technologies use for all categories of surveyed agricultural enterprises is 51.2%. The most popular technologies are electronic field maps, which are used more by medium and large agricultural companies. It should be noted that among certain groups of farmers, the level of digitized field maps reaches 91-95%. Only 20-30% of surveyed farmers are engaged in soil compaction mapping

(Netherlands Enterprise Agency, 2021). Farmers should support moisture sensors in their fields more. According to statistics on foreign experience of precision farming, in 2006, more than 80% of farmers in the United States used such technologies, which helped to increase grain yields to 90 c/ha. It has been proven that the costs of precision farming technologies can be recouped within 2-4 years after their introduction (Tsilyuryk, 2023). In accordance with experts, the precision agriculture market is expected to reach USD 21.9 billion by 2031, an increase of 10.7% compared to 2023 (USD 9.7 billion) (Netherlands Enterprise Agency, 2021). In order to spread the use of precision farming, foreign companies entering the Ukrainian market need to:

- find a representative or dealer of services (equipment) who can maintain direct contact with farmers and provide technical support for the operation of this equipment;
- establish cooperation with existing educational projects, participate in exhibitions and events to present technologies for the development of precision agriculture;
- clearly define the pricing policy in Ukraine so that the price of the product/service is clear and affordable compared to the price of competitors;
- apply to local authorities for financial support to purchase the latest technologies;
- develop partnerships with local governments to obtain up-to-date data on harvesting progress, as well as land use violations, burning of crop residues;
- unite the efforts of groups of farming companies, which will provide additional benefits for getting closer to local governments and large agricultural holdings.

Consequently, the use of modern technologies such as satellite imaging, sensors, GPS, and information technology to precisely manage crop production and resource use can help reduce the use of fertilizers and pesticides.

The use of organic farming, GMOs and the transition to alternative energy sources in the agricultural sector. Ukraine's state planning documents in the field of biodiversity conservation, in particular, the extent to which they meet the priorities and objectives of the European Green Deal, namely the EU Biodiversity Strategy 2030 (2020), show that one of the goals for Ukraine is to achieve a high level of organic farming. As of 2023, this figure is 8% for EU countries and 1.1 for Ukraine. The Strategy states that the goal for the EU by 2030 is to increase organic farming to 25%, and for Ukraine – to 3%. Organic production is developing in Ukraine. The share of agricultural land is the part of the land area (including arable land, pastures or wild areas) that is cultivated according to specific organic standards. The share of such land varies from year to year, depending on various factors affecting agricultural development (Table 2).

Table 2. *Use of organic agriculture in Ukraine, 2009-2022*

Name of the indicator	2009	2010	2018	2020	2021	2022
Total agricultural area, ha	41,280,000	41,280,000	41,330,000	41,310,000	41,310,000	41,000,000
Organic agricultural area, ha	270,190	270,230	233,500	410,580	370,110	263,619
Share of organic agricultural area, %	0.7	0.7	0.6	1	0.9	0.6

Source: *compiled by the authors based on Organic agricultural area, Ukraine, 1992 to 2021 (n.d.), Area of organic land and the number of operators decreased in Ukraine – Results of 2022 (2023)*

Table 2 shows that in 2020, the area of certified agricultural land growing various organic products was the highest in the last decade (over 400 thousand ha), which placed the country in 20th place among the world leaders in organic farming. In 2022, the area under organic production decreased by almost 40% and accounted for about 0.6% of the total agricultural land. This is primarily due to the outbreak of hostilities in Ukraine, the occupation of a large territory and shelling, which made some land unusable. Comparing the area of agricultural land under organic farming in other countries, it is worth noting that, for example, in Poland, this figure is 3.79%, in Romania – 4.42%, in Hungary – 5.82%, in Slovakia – 13.45%, in the Czech Republic – 15.81%, i.e. significantly higher than in Ukraine. The use of biotechnology, in particular genetically modified organisms, plays an important role in the new green economy, as the cultivation of GMOs is a step in agriculture towards increasing yields, increasing plant resistance to pests or drought, reducing the need for pesticides and fertilizers, and gaining other economic and environmental benefits (Litvinova *et al.*, 2023).

The seminar "Biotechnology in the agricultural sector: international experience of state regulation and market development" noted that if used in the EU at the level of, for example, North America, total greenhouse gas emissions could be reduced by 7.5% of their total volume, which is 33 million tonnes of CO_2 annually. Studies have shown that the agriculture index for EU countries increased by 7% between 1995 and 2019, while the same indicator in the US increased by 38%. In the US, GMOs have been grown and consumed for the past 30 years (since 1994). GM crops are a key factor in mitigating climate change (Tsybulska, 2023). In recent years, no

GMO products have been registered in Ukraine, despite the fact that such products were available on the market. Thus, according to the United States Department of Agriculture (USDA) Biotechnology and Other New Production Technologies Annual report, unofficial GMO cultivation in Ukraine is about 50-65% GMO soy, 10-12% rapeseed, and less than 1% GMO corn (GMO policy in Ukraine, 2024). In the context of European integration and the approximation of Ukrainian legislation to EU requirements on GMOs, the Verkhovna Rada of Ukraine adopted the Law of Ukraine No. 3339-IX (2023) on 23 August 2023, which will come into force on 16.09.2026.

The implementation of the Law contributes to the achievement of systematic compliance of Ukrainian legislation with EU requirements in the field of GMO cultivation and handling, as the Law of Ukraine No. 3339-IX (2023) is based on 8 key EU regulations in the field of GMOs. The Law provides for European mechanisms for the state registration of GMOs, establishing requirements for the use of labelling "with GMOs", "without GMOs", "produced from GMO raw materials", according to the rules followed by agricultural producers in the EU. The implementation of the Law of Ukraine No. 3339-IX (2023) is expected to increase the efficiency and transparency of state regulation procedures in the field of GMOs. In the context of the green economy, it is important for the agricultural sector to use renewable energy sources, which are produced from sources that are renewable and do not pollute the environment as much as nuclear power plants. Consumers, including agricultural enterprises, are shifting from fossil fuels to green energy around the world to reduce their impact on climate change and air and soil pollution. In terms of renewable energy, the EU has set a target to increase its renewable energy share from 32% to 42.5% by 2030 (Table 3).

Table 3. *European countries that are leaders in the use of alternative energy sources*

Country	Utilization rate	Main sources
Norway	75.8	hydro, wind, solid and liquid biofuels, as well as heat pumps
Sweden	66	
Finland	47.9	water, wind, and solid biofuels
Latvia	43.3	hydropower
Denmark	41.6	wind and solid biofuels
Estonia	38.5	
Portugal	34.7	solid biofuels, wind, hydro, and heat pumps
Austria	33.8	hydro and solid biofuels

Source: *R.A. Hughes (2024)*

As can be seen from Table 3, wind, hydropower and solid fuels are the main renewable energy sources in Europe. The average rate of renewable energy use across European countries is 23%. By 2050, the EU aims to become the world's first climate-neutral continent under the European Green Deal. The use of renewable energy helps to diversify energy supplies, which is extremely important in times of increasing energy shortages, which is relevant for Ukraine. However, in Ukraine, the percentage of renewable energy use remains low (about 15%) (Fig. 3).

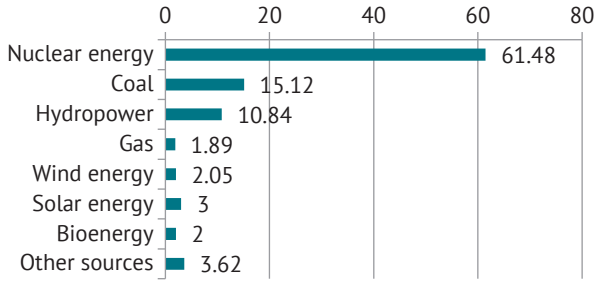

Figure 3. *Structure of electricity generation in Ukraine in 2023*
Source: *compiled by the authors based on Statista (n.d.)*

Fig. 3 shows that nuclear power remains the largest source of energy in Ukraine, while renewable energy sources still need to be further developed in their use.

Explosives contamination in the agricultural sector and identification of the main areas for improving the prospects for implementing a green economy in the agricultural sector in Ukraine. Explosives contamination of soil has a negative impact on the improvement of environmental sustainability in the agricultural sector. For example, military operations in Ukraine have contaminated more than 5 million ha of agricultural land. According to preliminary estimates by the Ministry of Environmental Protection and Natural Resources of Ukraine (n.d.), the full-scale military invasion caused damage to agricultural land in Ukraine in excess of UAH 19 million. Scientists say that even if a munition does not explode or explodes incorrectly, about 20-40% of hazardous substances enter the soil. The impact on Ukrainian soil from military operations can be distinguished by the following types:

- physical impact – creation of trenches and ditches, soil compaction from heavy machinery;
- fires – burning the top layer of soil fertility;
- chemical pollution – toxic elements, explosives.

Research on the impact of military equipment on soil was conducted in the United States, using a 57.2 tonne M1A1 tracked tank. The results confirmed the negative impact on medium and heavy loamy soils after just 1 pass of the vehicle. Soil compaction resulted in the formation of less biomass of vegetation cover (Ministry of Environmental..., n.d.). Heavy metal pollution is also significant: the bullets release lead, which is then absorbed by plants. In addition to lead, other metals enter the soil, such as chromium (Cr), mercury (Hg), nickel (Ni), arsenic (As), zinc (Zn), and others. Plants can accumulate heavy metals. Based on the analysed data on the implementation of the green economy in agriculture in Ukraine and the factors that can accelerate this process, it is advisable to draw up an action plan for the implementation of the green economy in the agricultural sector of Ukraine for the next 10 years (Table 4).

Table 4. *Action plan for the implementation of the green economy in agriculture until 2034*

Direction of the event	Characteristics of the event	Estimated completion date
Training and professional development	Training of agricultural workers and managers of agricultural companies on the essence and methods of applying green technologies	Constantly
Assessment and planning	Evaluation of methods and technologies for improving the environmental friendliness of agriculture and planning the introduction of new technologies	2024-2026
Transition to organic and precision farming	Use of organic fertilizers, crop rotation, digitization of land plots, use of satellite equipment, drones.	2024-2028
Changing approaches to cultivation and tillage	Introduction of drip irrigation to conserve water, cultivation methods that reduce soil erosion, GMO cultivation.	2024-2029
Use of renewable energy sources on farms	Installation and expansion of wind and solar power generation equipment	2024-2034
Restoration of soil from physical impact, fire, and chemical contamination	Mine clearance of the territory. Digitization of sites using satellite equipment. Analysis of the content of pollutants. Analysing the possibilities of farming in certain areas and their further intended use. Disposal of contaminants from the soil and restoration of damaged areas for further use	After the cessation of hostilities in a certain territory

Source: *compiled by the authors*

Table 4 presents a list of measures that need to be taken in Ukraine to continue the trend of greening the agricultural sector in the next 10 years. The ongoing military operations in Ukraine have a particularly negative impact, which is difficult to counteract even with the accelerated transition to organic farming, increased use of new technologies and other measures. Restoration of soil fertility after the war is expected to take decades, depending on the area that has been damaged, polluted and destroyed. This will require significant financial investments, for which the Government should be prepared, as it is difficult to imagine the recovery of the country as a whole without restoring agriculture. Thus, the assessment of the prospects for introducing a green economy in the agricultural sector has shown that Ukraine has already made many steps in this direction, but at the same time, it is necessary to increase the area cultivated organically, apply innovative technologies for precision farming, expand opportunities for the use of alternative energy sources and other measures. To this end, an action plan has been developed to guide the development of the agricultural sector in line with the requirements and trends of the green economy.

DISCUSSION

Improving agricultural production in Ukraine to align with the principles of the green economy is crucial, especially as the demand for increased agricultural output rises and the challenges of field cultivation and harvesting in conflict regions become more pronounced. The findings of this study suggest that the proposals are aimed at expanding the opportunities for implementing the green economy in agricultural production to meet sustainable development goals. The paper emphasizes that the green economy concept is a vital tool for achieving sustainable development goals globally, irrespective of a country's development level. N. Houssam *et al.* (2024) reached similar conclusions, noting a link between the green economy and three variables: gross domestic product (GDP) per capita, overall unemployment, and poverty. While supporting this view, it is important to note a statistically significant negative relationship between the green economy and poverty in developing countries. In formulating a green economy strategy for the agricultural sector, I. Smolii and N. Dikhtyarenko (2023) identified targets for the near future, including increased resource efficiency, reduced energy dependence, and enhanced export potential of the agricultural sector. However, the current level of financial support for green economy measures is insufficient.

The study highlights the benefits of the green economy for the environment, product environmental friendliness, and public health. Scholars' opinions on

the green economy's impact on economic growth are divided: some believe green growth can be achieved without compromising economic growth, while others argue that sustainable development cannot occur if intensive consumption continues to drive economic growth. C.I. Fernandes *et al.* (2021) contend that technology transfer and sustainable innovation contribute to green growth, positively impacting economic growth —a perspective that merits agreement.

Humanity's environmental pressure on the planet has been increasing, elevating environmental threats. At this stage, green innovations are seen as the optimal solution for sustainable development, combining economic growth and environmental protection (Bochko *et al.,* 2024). A. Koseoglu *et al.* (2022) demonstrated that economic growth is the main cause of environmental degradation, while urbanization has no statistically significant impact, and renewable energy consumption mitigates the ecological footprint. M.J.G. Wani *et al.* (2024) also emphasized the role of foreign direct investment and globalization in the G7 economy, noting that green economic growth is essential for sustainable development and that green energy positively contributes to green economic growth in both the long and short term.

The study underscores the importance of precision agriculture, which can positively impact the adoption of a green economy in agriculture. The conclusions drawn are supported by other authors, as precision agriculture has the potential to meet the growing demand for food sustainably, using a more accurate and resource-efficient approach to agricultural management. Smart farming technologies optimize this process, as confirmed by A. Monteiro *et al.* (2021), who reviewed the latest scientific and technological trends in crop production and developed proposals for farmers on applying technology in agriculture.

The article highlights that precision farming technologies can significantly reduce pesticide use. However, E. Anastasiou *et al.* (2023) stress that the adoption of these technologies by the farming community is crucial and requires proper incentives to encourage wider acceptance of green technologies among farmers. The study underscores the importance of using drones in agriculture for monitoring plant conditions and processing levels, noting that farmers who cultivate larger areas tend to use drones more frequently. Supporting this, M. Michels *et al.* (2020) studied drone use among large German farmers, finding that factors such as the farmer's age, knowledge of precision farming technologies, and farm size influence the adoption process. Similarly, A. Bai *et al.* (2022) examined drone use in Hungary, confirming that farm size, age, main job, and education level affect drone usage frequency. Emphasizing the importance of transitioning to precision agriculture, certain factors can either facilitate or hinder this process. R.W. Verburg *et al.* (2022) point out that diversifying certified products and government support through subsidies are key to scaling up precision agriculture. M. Gemtou *et al.* (2024) highlight the need to encourage farmers to adopt sustainable practices, while T. Begho *et al.* (2022) identify financial, personal, and agronomic factors as potential barriers, noting that advice and training, soil quality, irrigation, income, and credit can facilitate the adoption of new practices.

To reduce agriculture's environmental impact, the article advocates for organic farming practices, such as fertilizing soil with compost, using green fertilizers, and implementing crop rotation technologies. Despite the benefits, not all farmers are transitioning to organic farming, influenced by various factors. R. Sapbamrer and A. Thammachai (2021) identify relevant factors including gender, income, education level, positive attitudes, normative and moral obligations, organic farming experience, production costs, and farm ownership, along with technology support and competition from organic farmers. M. Canavari *et al.* (2022) similarly emphasize the importance of personal characteristics such as age, education level, and perception of bureaucracy.

When considering factors that influence the adoption of cleaner production technologies, Z. Niu *et al.* (2022) emphasize the need to account for these elements. The study reveals that in foreign countries, including Ukraine's geographical neighbors, the area under organic cultivation is significantly larger than in Ukraine. However, these countries face similar challenges. For instance, G. Király *et al.* (2022) found that in Hungary, the transition to organic farming is not motivated by the perception of adverse weather events. Additionally, A. Mazurek-Kusiak *et al.* (2021) note low demand for products from certified organic farms in Poland and Hungary, leading to decreased motivation among farmers to adopt organic practices. They also highlight main barriers to establishing organic farms, such as the need to adapt to EU requirements and the use of only natural fertilizers.

A study on the prospects of transitioning agricultural production to a green economy has revealed that biotechnology and GMO cultivation can enhance crop yields, improve resistance to pests and diseases, and reduce the need for chemical treatments. W. Yali (2022) supports this position, noting that, if used properly, GMOs can boost the economy without causing significant harm. However, the full potential of GMOs requires thorough research. N.J.C. Pardo *et al.* (2023) emphasize that GMO introduction must consider environmental and social sustainability unique to each area. In Lebanon, R.J. Roberts and V. Naimy (2023) found that GMOs improve plant resistance to weather and pests, reduce pesticide use, eliminate the need for chemical fertilizers, increase yields, and enhance the nutritional value of products. However, as M. Liu and H. Liu (2024) note, farmers' acceptance of GMOs depends on perceived value, but financial support from

state and local governments can facilitate adoption by mitigating perceived risks.

Therefore, encouraging the use of GMOs and other green technologies in agriculture should involve government or community support, adapting these technologies to local conditions, and improving the system of agricultural machinery maintenance, research, and development, as argued by P. He *et al.* (2021). The transition to alternative energy sources in agricultural enterprises is also crucial, especially given the electricity shortages in Ukraine due to infrastructure attacks. Achieving global goals, such as increasing renewable energy production and promoting sustainable development, relies on using natural gas as a transitional fuel to renewable energy (Kovalenko & Khandogina, 2022). R.R. Esily *et al.* (2023) concur, noting that carbon and natural gas emissions, ICT trade, and urbanization positively correlate with economic progress, although renewable energy has a negligible impact. Thus, intensifying efforts to use natural gas as a transitional fuel is recommended.

L. Chandra Voumik *et al.* (2022) also studied the environmental impact of increased energy consumption, emphasizing the need to reduce carbon emissions among various approaches to developing Bangladesh's economy and improving environmental quality. M. Mohsin *et al.* (2022) highlight that public spending on research and development of sustainable energy resources will result in low carbon emissions through improved production processes. In conclusion, the study indicates that to improve prospects for a green economy, measures such as expanding precision and organic farming, transitioning to alternative energy sources, and cultivating GMOs should be implemented. These steps will reduce environmental pollution, increase yields, and enhance the environmental friendliness of agricultural products. The study's results align with findings from other researchers, both Ukrainian and foreign, highlighting the importance of these conclusions for developing the agricultural sector during martial law and post-war recovery.

CONCLUSIONS

The study indicates that the development of green technologies in Ukraine's agricultural sector over the past decade has shown a trend of increasing and expanding various approaches to enhance the environmental friendliness of soil cultivation, crop fertilization, crop monitoring, and energy source selection. The goal and technology analysis set forth in this paper lead to several key conclusions. Understanding the fundamental principles of the green economy has allowed for the formulation of development directions for green technologies in agriculture and increased utilization of natural resources in soil cultivation and energy production.

An analysis of precision agriculture usage shows that farmers with larger agricultural land areas are more prepared to adopt these technologies, with their usage frequency being 2-3 times higher than that of smaller farmers. The average level of precision farming technology application in Ukraine across all categories of agricultural enterprises is approximately 51.2%, which is 30 percentage points lower than in the United States, where 80% of farmers utilize these technologies. The study found that the area of land under organic production in Ukraine is quite small (about 0.9%), and since the onset of the full-scale Russian invasion, this has decreased to 0.6%. This decrease reflects two main wartime obstacles: reduced safe cultivation areas and diminished farmer willingness and financial capacity. The article analyses the use of GMOs in Ukraine to increase yields, revealing that their adoption level is relatively low. However, it highlights the positive impact of the government's relevant legislation regulating the cultivation and sale of GMOs. It also establishes that alternative energy sources in agriculture help reduce financial costs and environmental emissions. Currently, nuclear energy comprises the largest share (61.5%) of Ukraine's energy structure, while alternative energy sources account for about 5%, which is low compared to other countries.

The study points out that the most negative impacts on the environment, soil quality, and green technology development in agriculture stem from pollution caused by explosives, fires that burn the top fertile soil layer, and field compaction from heavy machinery. To improve the prospects for implementing the green economy in agriculture, an action plan is proposed in the following areas: training and professional development; assessment and planning of methods and technologies to improve agricultural environmental friendliness; transition to organic and precision farming; use of renewable energy sources; and restoration of soil from physical impact, fire, and chemical pollution. These measures will accelerate the introduction of a green economy in the agricultural sector over the next 10 years and enhance the competitiveness of Ukraine's agricultural sector. However, the study on financing the adoption of green organic and precision farming by farmers remains promising and requires further exploration. To improve the accuracy of the study results, it is essential to investigate ways to encourage farmers to use green technologies. Future research should focus on a more detailed examination of the factors influencing farmers' choices regarding green technologies.

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CONFLICT OF INTEREST

None..

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Перспективи впровадження «зеленої» економіки в аграрний сектор України на найближчі 10 років

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Анотація. Актуальність дослідження зумовлена погіршенням екології та низьким рівнем застосування «зелених» технологій в аграрному секторі України. Метою було окреслити актуальні проблеми для фермерів при використанні «зелених» методів ведення агрогосподарства та знайти їх вирішення. У дослідженні оцінювався рівень використання окремих «зелених» технологій в процесі аграрного виробництва в Україні. Головними результатами, отриманими у цій праці, слід вважати: визначення місця України у рейтингу Індексу зеленого майбутнього за різними напрямами протягом 2021-2023 років та порівняння його з Ісландією, Фінляндією та Норвегією; виявлення напрямів «зелених» технологій, які необхідно розвивати в Україні в період воєнного стану та після війни (прецизійне та органічне землеробство, впровадження біотехнологій для створення генетично модифікованих організмів та перехід на альтернативні джерела енергії). Вивчення залежності схильності фермерів застосовувати «зелені» технології від величини фермерства підтверджує її безперечну наявність. Аналіз зарубіжного досвіду застосування точного землеробства дозволив сформулювати рекомендації щодо поширення використання точного землеробства в Україні для іноземних компаній, які виходять на український ринок. Висновки про зростання дефіциту електроенергії сприяли обґрунтуванню подальшого використання альтернативних джерел енергії в умовах. Дослідження негативного пливу бойових дій на українські землі дозволило класифікувати такі види впливу та розробити заходи щодо відновлення ґрунту. Оцінка застосування технологій у сільському господарстві спряла виокремленню напрямків для впровадження «зеленої» економіки в аграрному секторі в Україні, які сприятимуть підвищенню врожайності сільськогосподарської продукції без шкоди для екології та підвищенню її конкурентоспроможності. Результати та висновки мають практичну значимість для Уряду при розробці аграрної політики та працівників сільськогосподарських підприємств при веденні господарства

Ключові слова: прецизійне землеробство; сільськогосподарська продукція; інноваційні технології; відновлювальна енергія; добробут; врожайність