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Environmental footprinting of agri-food products traded in the European market

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Sustainable food principles and requirements established by the European Union are becoming a standard for all foodstuffs available on the EU market, and it should be taken into account by countries exporting agri-food products, such as Ukraine. The aim of this article is to generalize European milestones for defining sustainable foodstuffs, revealing their key differences from ecological/organic products, differentiating products in the carbon footprint level, and substantiating challenges for exports of agri-food products to the EU in terms of positioning their sustainability. The European market features an increasing differentiation of agri-food products in terms of sustainability and ecology, particularly carbon footprint indicators, which are examined in this article. More stringent monitoring of chemical pesticide and antimicrobial residues in products exported to the EU could be a challenge as the use of these products is expected to be reduced by 50% by 2030. This study substantiates the risks for agricultural production and exports in Ukraine caused by the differentiation of agri-food products in their sustainability indicators, enhancement of monitoring the level of residues of pesticides and active ingredients of veterinary drugs in agri-food products, and limitation of agri-food and agricultural raw material exports to the EU because of heavy greenhouse gas emissions during crop cultivation to produce biofuel. This study analyzes the economic growth of agri-food products that will take place only in the case of avoiding the impoverishment of natural resources, which is formalized based on the Robert Higgins' model. The results of the research can be used for further strategic planning in the field of agricultural production with environmental regulation.

KEYWORDS

sustainable agri-food products, environmental footprint, greenhouse gas emissions, EU Green Deal, natural resources

1 Introduction

The problem of the use of outdated technologies that worsen the environmental condition in Ukraine had an accumulative nature and was consolidating over a long period. At a time when legislation was being improved in European countries, new equipment was purchased for enterprises, corruption ties related to ecology were consolidated in Ukraine, and no significant changes were observed. Nature was constantly negatively affected. The accumulation of carbon dioxide became the cause of climate change, and developed countries began to introduce changes in production, while poorer countries were still generators of harmful substances. Economic growth under the current conditions of ecological limitations is possible only in the case of avoiding impoverishment of natural resources. The cost of products in developed countries show real expenditures on natural resources, expenses for safety, and compensation for environmental pollution, as well as social and climate expenses. Considering all expenditures, the cost of unsustainable products (e.g., red meat) can be higher, resulting in a decreasing demand for them.

In Ukraine, the production of agri-food products has an environmental impact, which is currently not indicated in environmental certificates and can be reduced by classifying products and developing mitigation measures in each category.

Green transformation according to the EU Green Deal, given the environmental and climatic aspects of manufacturing and supplying products as well as setting new values and prices, is characterized by enhancing the differentiation between sustainable and unsustainable agri-food products in European and global markets. Sustainable food principles and requirements established by the European Union are broader than ecological/organic ones because, in addition to being environmentally friendly, they include climatic and social characteristics. The key difference is the significance of the climatic criterion for sustainable products: reduction in greenhouse gas emissions during agri-food production and supply (and other carbon footprint parameters), which corresponds to the main goal of the EU Green Deal aimed at decarbonization and achieving the climate neutrality.

It is problematic to bring together approaches to the sustainability of foodstuffs with the standard methodology. Obviously, the stipulated methodology for defining sustainable products is based on the aggregate of food (nutritive value marked, for example, according to the five-stage Nutri-Score scale), climatic (volumes of greenhouse gas emissions, *etc.*), ecological (application of chemical pesticides, prevention of land degradation, and biodiversity loss, *etc.*), and social (observance of employees' rights, especially women and non-use of child labor, *etc.*) parameters.

In developed countries, in any production, they evaluate the consequences, study the impact on the ecosystem, and use the most green technologies and methods to improve the quality of life, while developing countries use their resources with minimal control over their condition, which causes the degradation of nature (Garcia-Llorente, Rubio-Olivar, Gutierrez-Briceno, 2018).

At present, it is very important to use the seasonality of agricultural products, which is reflected in the price of the product and is less subjected to chemical influence, thus making them of high quality. Therefore, in order to reduce negative consequences, it is necessary to create new products in natural ways, which are now popular in Europe (Peeters et al., 2020). This actualizes preparations of agricultural entities to refocus on manufacturing and exports to the EU based on the systematization of the EU requirements as part of the EU Green Deal for sustainable agri-food products and their certification in terms of sustainability indicators (environmental, economic, and social), which should be considered by Ukrainian producers and exporters of agri-food products.

The aim of this study is to generalize European milestones for defining sustainable foodstuffs, revealing their key differences from ecological/organic products, differentiating products at the carbon footprint level, and substantiating challenges for exports of agri-food products to the EU in terms of positioning their sustainability.

The key approaches to sustainable foodstuffs are initially stipulated in the EU Farm-to-Fork strategy, and other available documents within the EU Green Deal will be eventually formed in the set of requirements (criteria). The broader concept of sustainable products compared to the ecological ones is revealed in the article, generalizing their differences. This approach makes it possible to study the content and components of the environmental footprint, in particular, the carbon footprint, since the EU has established a methodology for comparative assessment of this footprint of products and companies in order to assess their sustainability. The EU Green Deal declares the reduction in climatic (volumes of greenhouse gas emissions) and ecological (in particular, application of chemical pesticides) parameters as important characteristics of product sustainability. Despite the positive experience of developed countries, changes occur more slowly in Ukraine, and their implementation requires attending to the realities of this country, adaptation, and systematicity.

2 Literature review

The identification of agri-food product categories and the review of literature sources dedicated to sustainable foods, which are the basis for the EU legislative framework and differ from ecological/organic products, allowed detection characteristics considering climatic (greenhouse gas emissions) and social (observance of employees' rights) parameters of product sustainability (Lex, 2020).

Sustainable products are frequently mentioned in the context of sustainable diets (HLPE, 2017) and the promotion of foodstuff

advantages by business companies and their innovativeness in plant-based meat substitutes, dairy-free cheeses, and insect-based products, *etc.* In addition, there is a lack of an official definition of sustainable nutrition and emphasis on the aspects of restoration and regeneration and the realization of environmental, social, and economic values in society (Syed, 2020).

The definition of sustainable foodstuffs is given (Vermeir et al., 2020) as those meeting the basic needs, improving the quality of life, and minimizing the use of natural resources, toxic materials, emissions of wastes, and pollutants throughout the life cycle, in order to prevent threatening of the needs of future generations (Vermeir et al., 2020). Sustainable foodstuffs are eco-friendly products that minimize greenhouse gas emissions, rationally use resources, and focus on the rights of farmers and their salaries, methods of cultivation, and animal slaughtering (Meredith, 2020). Also, sustainability parameters such as minimizing the number of food miles are considered. Therefore, the main products must be produced in that country seasonally (Finney, 2021). Ultra-processed foods must be avoided, and sustainability certifications should be checked (Author anonymous, 2019). Martinho (2019) stated that despite the large number of studies exploring the reduction in the negative ecological impact on agricultural production, there are still many unexamined matters, particularly the practical value and proper classification, which can improve the selection of a method for solving production waste issues. The research concludes that the impact of industrial emissions and waste disposal on health of the local population is quite acute in Ukraine because of problems with the medical system undergoing transformation (Atstaja et al., 2022). Pata concluded that when considering the problem of irrational natural management in the long term, one can see increasing pollution indicators.

Thus, agriculture should be maximally used in further waste management processes to reduce the environmental impact (Pata, 2021). Researchers asserted that the constant increase in the demand for livestock products has a significant ecological footprint that should be additionally examined, considering both positive and negative consequences of a certain region owing to the limited amount of agricultural land and its maximum efficient use (Pogue et al., 2018). Li et al. (2020) claimed that to control the environmental footprint, manufacturing enterprises should apply sensors and analyze the chemical content of soil and air. It is referred to contemporary automated systems that are sensitive to changes can be upgraded and can also be used in Ukraine's agricultural enterprises.

The constant interaction of the natural environment and agricultural production leads to changes in ecosystems and can have both negative and positive consequences. We can observe different development scenarios and control biocenosis and soil composition by adjusting agricultural production as claimed by Aizpurua et al. (2018).

As observed by the scientists, emissions from the production of agricultural products are related to the production capacity and the nature of the product obtained. There is a positive correlation, which confirms the negative ecological footprint and creates the need for a change in technology (Xu B et al., 2017).

Despite numerous studies on the aforementioned issues, this study analyzes the areas of soil remediation in the territories negatively affected by production operations based on the principle of production waste–air purification–soil cleaning–water system purification–biocenosis control and assesses the impact of agricultural production on the ecosystem *via* the economic efficiency indicator according to groups of agricultural products.

3 Research methodology

This research analyzes contemporary methods for assessing the impact of various groups of agricultural products, such as the production of meat products, milk, tomatoes, and corn, on the environment. The assessment is based on analytical methods that group the studied indicators and draw conclusions. To create a mathematical model, the methods of mathematical analysis and statistical research were used. This study applies modeling methods to analyze the potential of the Ukrainian agricultural sector and define agricultural production problems that have the environmental footprint investigated using analytical, statistical, and comparative techniques.

The approach was to study the conceptual and terminological apparatus behind the topic of "sustainable agri-food" since it was not presented in a comprehensive manner, as it turned out when studying literary sources. Assuming that there are entrepreneurial initiatives to promote their products with a focus on sustainability, it was important to collect the available evidence for food sustainability positioning and certification. The analytical part of the study was particularly difficult because it used some of its environmental and climatic indicators for analysis due to the lack of standard methods for quantitative assessment of food sustainability. To reduce companies' misrepresentation of their food products as sustainable, more scientific research works for reliable, comparable, and verifiable indicators of sustainability were required. The practical part of the analysis involved assessing the risks for Ukrainian exports in the event that the EU sustainability requirements for agri-food products were strengthened.

Owing to constantly growing production and consumption of foodstuffs, an increase in greenhouse gases that can lead to global ecological consequences is observed. Therefore, greenhouse gas emissions are examined per kilogram of the product. The assessment of greenhouse gas emissions is calculated separately for each product and is shown in tables,

which can later be structured and presented in a mobile application to inform the population about the nutritional value and viability of food production more efficiently. To structure, group, and classify the obtained data, one takes a systematic approach based on the combination of statistical, induction and deduction, synthesis and analysis, analogy and abstraction, and mathematical methods of data analysis. The process of creating information has a generalized system approach, and the research results are based on the developed classification, which defines the environmental footprint. It is viable to make these products for further strategic planning in the agricultural sector and regulation of ecological, economic, and social risks with the possibility of their optimization and minimization. The analysis of the ecological footprint can be considered at the quantitative estimation of environmental risks, which proves the viability of applying agricultural production methods in Ukraine. The analyses of theoretical materials, reports, and statistical data are used to comprehensively define problems and methods of rational natural management, adopt sustainable production in the agricultural sector, and shift it to the principles of eco-friendly development, which allows the construction of several models for developing a further situation in Ukraine based on the literature review and research. The article uses mathematical modeling methods to create analytical dependencies between the studied indicators. Complex scientific and cognitive research methods were also used, which was reflected in the analysis of the potential of the agro-industrial complex of Ukraine, the capabilities of developed countries, and the problems of agricultural production that primarily have an ecological footprint, which was investigated by analysis, comparison, and statistical methods. A systematic approach based on a combination of statistical methods, methods of induction and deduction, synthesis and analysis, analogy and abstraction, and mathematical methods of data analysis was used for structuring, grouping, and classifying data. Public materials used for research, legal instruments, and concepts were analyzed both in Ukraine and abroad, which made it possible to comprehensively investigate this problem.

4 Research data

From the analysis of the literature, it is possible to hypothesize that by changing the approaches to agricultural production, it is possible to reduce emissions of carbon dioxide released into the atmosphere and correct the state of the ecosystem around the enterprise.

According to the United Nations, the average price of greenhouse gas neutralization using specialized systems for their collection and storage with further processing is approximately 45 USD (5–75 USD depending on the type of equipment) (Intergovernmental panel on climate change, 2021), which can be calculated as the cost of reducing the ecological load from production and considered while estimating the economic efficiency. However, only large enterprises and agricultural holdings can afford necessary equipment because of huge investments at the stage of designing purification systems, which set up barriers to private households. Nevertheless, due to the constant reduction in the cattle stock of local farmers, the pollution data from private households can be ignored when calculating the total cost of neutralizing negative effects from production.

Figure 1 shows the increase in crop production at the time interval and the decrease in crop production primarily due to the growth of crop yields in Ukraine, which will positively affect the amount of greenhouse emissions because of the significant difference between emissions during livestock and crop production.

Figure 1 shows the two-fold reduction in cattle production, which has the largest environmental footprint among other agricultural production indicators, increase in poultry production from 192 thousand tons in 2000 to 1,382 thousand tons in 2019, and two-fold increase in egg production during the analysis period. Figure 1 shows the increase in pork production by 32 thousand tons over 10 years. Considering the environmental footprint in Ukraine, we observe an increasing ecological burden due to the expansion of cultivated areas and decrease in the amount of forests and longstanding green spaces. At the same time, beef production as a product with the greatest impact on the ecosystem has become less substantial year by year, while the production of other livestock products has a smaller ecological footprint. In addition, the installation of modern systems for production waste neutralization makes this sector more promising for introducing eco-friendly businesses and changes.

Analyzing the production viability should consider expenditures to minimize the negative ecological effect, which can be shown in cash equivalent. Considering expenses for emission gas neutralization, we can obtain a decreasing profit from selling agricultural products. Figure 1 shows the highest selling price of meat production and the high production cost.

Figure 2 shows the change in the product selling price in 2010 due to the USD exchange rate changes in the country and economic and political changes in 2008. The increase in the product selling price compared to 2000 at the time interval is caused by the increase in the total income of the population, growing prices of agricultural products due to inflation processes, decrease in the amount of agricultural products by private farms, equalization of product prices caused by new export markets, and impact of global prices and trends.

The decline in selling prices in 2014–2015 was caused by political and economic shocks and the increasing USD to UAH exchange rate, while selling prices in Ukraine as of the analyzed period were presented in UAH. Thus, its dollar equivalent decreased lower but then grew in regard to many goods until 2021.

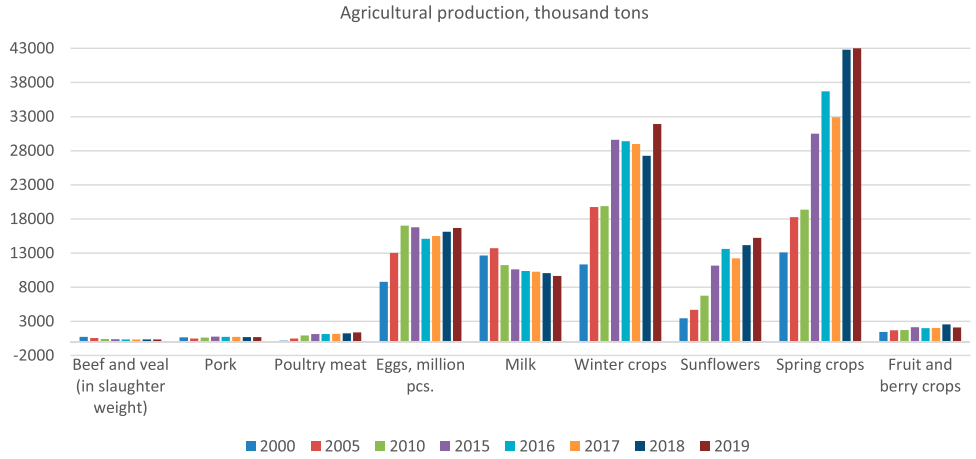

FIGURE 1
Production of key types of agricultural products in Ukraine (State Statistics Service of Ukraine, 2021).

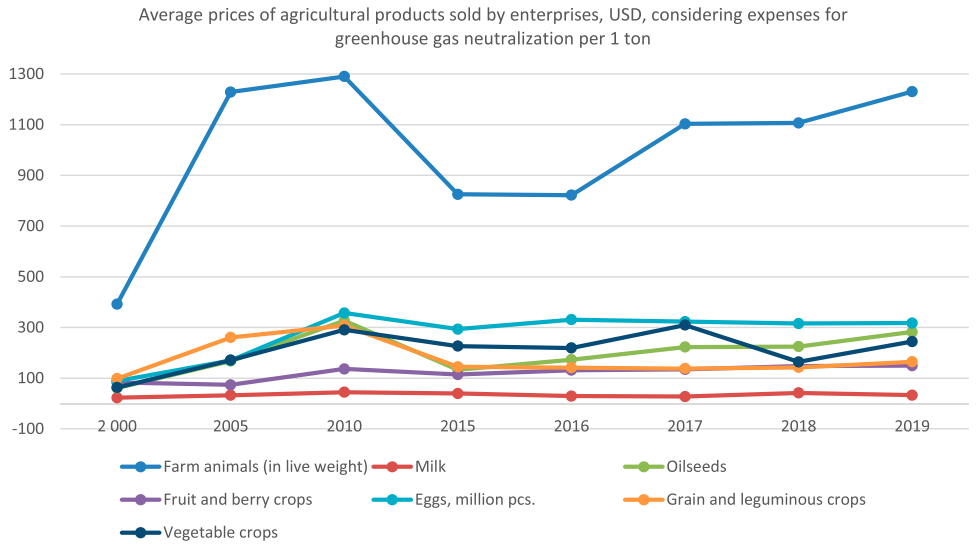

FIGURE 2
Average prices of agricultural products sold by enterprises, considering expenses for greenhouse gas neutralization, USD per 1 ton of products made (State Statistics Service of Ukraine, 2021).

Despite this fact, selling prices of most types of agricultural products in Ukraine are quite low compared to those of developed countries, which is, on the one hand, promising to enter global markets and, on the other hand, makes the agricultural production sector less profitable, creating barriers to the integration of resource-saving technologies. Thus, the production of beef products, including expenses for environmental footprint neutralization, is unprofitable and has loss-making performance with up to 30 heads, which is proven by the reduction in its production in the Ukrainian market (Figure 1). Profitability indicators of Ukrainian companies are gained, in case of the large turnover of products, by making poultry, leguminous crops, fruit, and berry crops (minimum ecological footprint), which indicates a problematic situation that does not promote eco-friendly production widely adopted in developed countries.

At the same time, Ukraine features the constant use of natural resources without its recovery, use of cheap and primary non-ecological fertilizers and feeds, and constant degradation of the natural environment.

5 Methodology

The methodological approach of the authors is initially based on the identification of the sustainable food category from the perspective of European documents, stipulated sustainability criteria (environmental, economic, and social), and generalization of foreign and national specialized literature sources. This part of research is aimed at promoting this narrow term in Ukraine, which is important in terms of untimely preparation of local agricultural manufacturers to comply with the European sustainability requirements that will be imposed on agri-food imported to the EU.

The study systematizes differences between agri-food products and ecological and organic products and reveals the existing experience in voluntary certification of product sustainability. The authors of this thematic research substantiate challenges for Ukraine and Ukrainian exports of agri-food products in the context of tougher requirements for the sustainability of these products, particularly the climatic aspect and carbon footprint, as well as generalizing steps stipulated by the Ukrainian government to minimize these challenges.

In case of further irrational use of natural resources, we can see a pessimistic scenario that will result in environmental degradation and further increase in expenses for environmental recovery and the creation of safe products, as well as health problems for the local population. The use of soil ameliorators leads to an imbalance in the chemical condition and worsening of the quality of groundwater arteries, biosphere changes, new diseases, and threats to agricultural products, which are crucial elements in the food chain.

In case of the adoption of cutting-edge technologies, systems for decreasing the environmental impact at newly established enterprises, and the gradual introduction of technological changes at existing enterprises, we could see the reduction in degradation processes by decreasing factors affecting the ecosystem, which will prevent the accumulation of toxic substances and undesirable effects. The environment will gradually recover from previous irrational natural management, create conditions for eco-friendly products, and provide a possibility for profit generation by enhancing the product quality and improving the social welfare.

In the optimistic scenario, which is less likely for Ukraine and illustrates the rapid change in current approaches to agricultural production, elimination of the negative impact on the ecosystem in the past, and changes in business operations and priorities of each citizen, we could see the rapid shift to sustainable development, i.e., eco-friendly technologies that should have better financial results in the long run. At the same time, they initially require huge investments, stable external and internal enterprise environments, subsidies and grant programs, and implementation of the ecosystem preservation concept in the entire territory of the country.

The first or second scenario is more likely to occur in Ukraine. However, the analysis of the environmental footprint of agricultural production and product labeling by the environmental effect can positively influence the choice of enterprises, farmers, and state-owned enterprises while developing the concept of further evolution in order to decrease the environmental burden and affecting the consumption of products and the agri-food market in general (Wang et al., 2022).

The hypothesis of this case study is that food products will also be included in the scope of sustainability assessments over time, given the already well-developed sustainability regulation of energy-related industrial products (such as electronics, furniture, and textiles). The new EU regulation, Ecodesign for Sustainable Products, proposed in 2022 (replacing the 2009 regulation), should improve circularity, energy efficiency, and other aspects of environmental sustainability for nearly all categories of physical products placed on the EU market. So far, the notable exception is food and feed as defined in Regulation EC/178/2002 (European Commission, 2002). The hypothesis about the following assessment of food sustainability was formed on the basis of the envisaged development (by the end of 2023) of a legislative proposal on the framework of a sustainable food system and the sustainability performance of food products, their certification, and labeling, as noted in the strategy "from the Farm to the Fork" as part of the European Green Deal. The assumption was that European farmers are better than Ukrainian farmers who are aware of the parameters of sustainability of food products and have been using sustainable farming methods for a long time; direct payments are made to them only if they comply with the requirements of "eco-conditionality" of support (the "cross-complaints"). It was assumed that the ignorance of Ukrainian agricultural producers may have created risks for them in promoting the export of agricultural products.

5.1 Higgins' model for agricultural development

The analysis of the economic growth of agri-food products can be formalized based on the Higgins' model (Higgins, 1977; Poore, Nemecek, 2018). Let the company's growth rate (z) depend on the net margin on sales (Rp), the share of dividends in net profit (d), correlation between rental (credit) and own capital (K, financial leverage), correlation between assets and profit (A, capital intensity), investments in the recovery of natural assets used in a certain period (Ec), sales prices of natural assets used or affecting goods, and depending on economic (manufacturing) activities in the competitive market (V, the amount of funds that can be obtained from the alternative use of natural resources).

$$z = \frac{Rp(1-d)(1+k)}{A - Rp(1-d)(1+k)} - \frac{Ec}{V}. \quad (1)$$

From Formula 1, we conclude that the economic growth combines both financial indicators and sustainability performance and can be considered the ecological and economic values depending on the profitability of the company's sales, dividend and financial policies, and efficient use of assets and natural resources. The indicator of the economic growth in the long term will progress with the introduction of resource-saving technologies and reduction in emissions and waste, which is the basis of the green economic system widely implemented in the European market.

When considering the production model at the input, we can calculate the amount of resources used in their material equivalent at market prices. Then, the output from the model is the product and waste, the amount of which is minimized at the green economic deal, which can be written as the correlation between the obtained useful product and the total cost of resources. Hence, the ecological and economic efficiency can be calculated given the negative emissions (waste) from manufacturing activities:

$$Ef = \frac{\sum_{k=1}^{K} \mu P_k - \sum_{l=1}^{L} \alpha R_l}{\sum_{i=1}^{N} V_i + E_i + \mu P}, \quad (2)$$

where Vi is the volume of emissions (waste) for a certain period expressed in cash equivalents, which shows the amount of funds required for their utilization; Ei is the negative indirect impact of production on other objects and natural resources expressed in cash equivalent (the amount of money required to neutralize all negative effects); μP is a vector of resource inputs to the model (the sum of resources used) expressed in cash equivalent at their fractional sales in the market in each manufacturing area at the enterprise (during diversification); and αR is a vector of finished product outputs expressed in cash equivalent at goods sales on the market at the studied time interval.

In this case, the economic value-added model (EVA) should also take into account the ecological effect when calculating the profitability of investment capital, which will have a less negative ecological effect in case of increasing investments in innovations, and this can be considered an economic indicator. The analysis results conclude that EVA of eco-friendly and innovative enterprises is more than 0 (EVA>0), which indicates an increase in the enterprise market value over the balance value in the long run and the prospects for the development of such an enterprise due to the minimization of waste and spread of investment profitability.

6 Results and discussion

6.1 Sustainable agri-food products: conceptual aspects and differences

The UN declared 2021 the International Year of Fruits and Vegetables, as it has a lower negative impact on the environment. Moreover, they do not require the expansion of cropland by deforestation and enhance food safety more efficiently per unit of land, water, and nutrients. According to Popp A. et al. (2010), developed countries shift or about to shift to healthy consumption models, particularly with the increasing share of plant products in the diet and the decreasing amount of foods with high sugar content and red meat. Unless consumption of these products is reduced or production technology is changed, greenhouse gas emissions from livestock will increase by 80% by 2050. This can lead to an increase in the Earth's temperature within 2°C, and the environmental footprint of agricultural production can exceed the acceptable values by 2070.

Therefore, the food system should substantially contribute to the reduction in greenhouse gas emissions and primarily carbon dioxide (CO_2) (decarbonization) by 55% by 2030 compared to 1990 and turn Europe into the first climatically neutral (absence of net greenhouse gas emissions) continent by 2050. As part of the Farm-to-Fork (F2F) strategy of 2020, a component of the EU Green Deal, is going to make the EU food system the global standard of sustainable development, and European food products will become the global standard of sustainable development. It is planned to reduce the dependence of their production on chemical pesticides and antimicrobials (by 2030, reduce their use by 50%) and fertilizers (by 20%), increase organic farming (up to 25% of agricultural land), increase farm animals, and stop the loss of biodiversity.

The European Green Deal will have a direct impact on Ukrainian exporters and, finally, on all agricultural producers in Ukraine. The reduction in the use of agricultural inputs envisaged by the European Green Deal may lead to a decrease in productivity and agricultural production in Ukraine. Exports will be constrained by stringent EU regulations to monitor the maximum levels of residues of pesticides and antimicrobials in agri-food products. The goal is that the European Green Deal on decarbonization and climate neutrality may cause a reduction in Ukraine's exports of corn and oilseeds as raw materials for biofuel production due to the high levels of greenhouse gas emissions from their cultivation. Ukraine needs to get rid of signs of unsustainable agriculture (a high level of plowing of the territory, a large share of degraded land in cultivation, and non-compliance with crop rotation, *etc.*). The necessary improvements in national agricultural policy and practice relate to meeting the requirements of the European Green Deal to reduce the use of agro-productive resources, conduct decarbonization and achieve climate neutrality, and promote the sustainability of agri-food products.

This is referred to as a decrease in the environmental and climatic footprint of the food system, assurance of a neutral or positive environmental impact at all stages of the food chain, and climate change mitigation. Sustainable foodstuffs should be affordable for consumers.

The Farm-to-Fork strategy applies such terms as sustainable foods and sustainability performance of food products,

TABLE 1 Key characteristics of sustainable and ecological (eco-friendly) products.

Sustainable product[a]	Eco-friendly/organic product
Socioeconomic, ecological, and climatic requirements are imposed on sustainable products. The requirements for eco-friendliness are less strict than those for ecological/organic products	There were no social requirements for organic products. Although these products play a triple social role, they fill a specific market according to consumer needs, ensure social welfare, encourage environmental protection, and provide jobs
Products should have a low environmental impact throughout their life cycle (pollutant emissions into the air, water, soil and saving and rational use of energy, water, and other resources)	Key requirements for organic production: no GMOs, preservatives, hormones, antibiotics, growth stimulators, no hydroponic production, and plant maintenance primarily *via* the soil ecosystem
To decarbonize the food chain, one takes into account CO_2 and other greenhouse gas emissions from agricultural production. Livestock production methods are carbon-efficient and ensure animal well-being (good health, comfortable living conditions, proper feeding, and safety)	Organic production rules in the context of eco-friendliness are as follows: prevention or minimization of environmental pollution, safety of soil degradation processes, and preservation and recovery of soil fertility
Products delivered to consumers as short supply chains. GMO requirements remain unknown. Thus, the production of sustainable goods is socially responsible	

[a]Mentioned previously are authors' way of categorizing characteristics of sustainable products generalized, following the results of the analysis of European documents on the EU Green Deal.

emphasizing the sustainability of foodstuffs subject to certification and marking. Sustainable foods can be sometimes interpreted as eco-friendly foodstuffs, which makes no sense. Earlier, the concept of ecological/organic product was associated with a sustainable product, but now these concepts are gaining their own essence. In its action plan for the development of organic production of 2021, the European Commission observes that organic farmers are pioneers in sustainable agriculture of the future. In addition to eco-friendliness, the sustainability of agri-food products is characterized by a wide set of parameters, namely, the social and climatic ones (Table 1).

Both greenhouse gas emissions throughout the product life cycle and social parameters are taken into account. According to amendments to the EU Common Agricultural Policy approved in June 2021, member countries can subordinate receiving of direct payments by agricultural entities to the observance of employees' rights from 2023, and this regulation will become obligatory within the EU by 2025. Sustainable products ensure environmental, social, and economic benefits, protecting public health and environment throughout their life cycle, from raw material extraction to final disposal. In particular, sustainable agri-food products mean that they are produced, sold, and distributed in compliance with sustainability guidelines and have the appropriate certification.

Sustainable products are not equal to ecological/organic ones, as the core interpretation of ecological products does not include requirements for greenhouse gas emissions and farmers' rights. Thus, sustainable foodstuffs are ecological and have additional characteristics. Products can be ecological, but if they consume a large amount of energy throughout their life cycle (from production to consumption), large volumes of greenhouse gases are emitted, particularly CO_2 (climatic aspect), and involve child labor and release local women (social aspect); then, such products are considered unsustainable. For example, beef produced in compliance with all requirements is recognized as an ecological product, although it is unsustainable because of non-fulfillment of environmental and climatic requirements (energy-consuming and carbon-intensive production).

Sustainable products can meet less strict requirements for eco-friendliness than ecological products, particularly for the application of chemical fertilizers. For example, Ritter Sport decided to abandon organic business in favor of sustainable business, justifying this policy by promoting the importance of sustainability and social guarantees and shifted away from organics. The company requested farmers from Nicaragua, who had been supplying cocoa since 1990, to obtain UTZ or Fair Trade certificates, although the farmers already had the organic certificate (biocertificate) (Kreuzer, 2017).

The example of unsustainable products is red meat (the Farm-to-Fork strategy stresses the necessity to reduce its consumption; it is referred to beef, pork, lamb, goat, horsemeat, and some parts of chicken (thighs and shins)). In addition, red meat belongs to unsustainable products largely because of negative ecological aspects (not only from the perspective of human health), huge consumption of energy and water, and heavy greenhouse gas emissions, particularly methane, during the breeding of appropriate farm animals. It is viable to increase the consumption of fruits, vegetables, grains, legumes, and nuts as more sustainable products (stipulated in the F2F strategy, the Code of Conduct regarding responsible food business operations and marketing practice).

6.2 Carbon footprint of different agri-food products

To calculate the production impact on the environment, European countries use the concept of the environmental footprint defined throughout the product life cycle. Trends in environmental footprint indicators (with components—soil, water, carbon footprint, and food miles) for a certain period

TABLE 2 Greenhouse gas emissions during the supply of agri-food products, kg (CO_2 equivalent per kilogram of the product).

Product	Volume of greenhouse gas emissions
Beef (meat)	60
Lamb	24
Cheese and cows (dairy farms)	21
Pork	7
Poultry and olive oil	6
Eggs and rice	4
Milk	3
Wheat, rye, and tomatoes	1.4
Corn	1
Peas and soy milk	0.9
Root crops and apples	0.4
Nuts	0.3

In accordance with Poore and Nemecek (2018).

show a shift to a sustainable food system. The carbon footprints of different agri-food products are shown in Table 2.

Table 2 shows that the largest share of greenhouse gas emissions (including methane and nitrous oxide) are generated while producing animal goods. Livestock farming also affects the area of forests and vegetation plantations (emissions from ground biomass change during deforestation) and makes changes in qualitative parameters of soil during excessive grazing, which results in land degradation. The carbon footprint is generated by methane emissions during animal breeding and utilization and emissions from agricultural machinery and food cultivation. Livestock products have a significantly more negative environmental effect than crop cultivation. The largest indicators of the carbon footprint can be seen while producing beef (60 kg of greenhouse gases throughout the product life cycle per 1 kg of the product) and pork and poultry—10 times smaller—at the level of 7–6 kg of CO_2 equivalent per kilogram of the product.

From the table, it can be concluded that it is rational to grow peas and other legumes and root crops, which positively affects the soil condition, and is eco-friendly and useful in human diet. Nut production is a negative indicator of land-use emissions, as walnut trees absorb carbon from the atmosphere, which is promising in the implementation of sustainable nature management. However, the carbon footprint in livestock farming can be reduced by changing the animal feed ration, prohibiting deforestation for cattle grazing, rationalizing the use of available areas, and upgrading farming enterprises (Tilman, Clark, 2014). Sometimes locally and traditionally produced foods can be more climate-friendly than ecological/organic products brought abroad. From the perspective of carbon footprint calculation, a type of consumed product is of greater importance than the place of its arrival (except for products delivered by air), as transportation accounts for a small share of emissions—less than 10% of the final product footprint on average—which can be neutralized by creating a model of environmental footprint calculation.

6.3 Analysis of the economic growth of agri-food products based on the Higgins' model

An analysis was carried out on 20 companies that are located in different regions but producing similar products (Figure 3).

The results showed that when neutralizing waste, the company's profit decreases in the short term, but the indicator of added value increases in the long term. Old technologies and extensive production have a negative impact on performance indicators in the long term, while natural production is resource-saving. Effective indicators do not decrease, which indicates a positive effect. Green technologies, or technologies of natural production, has become popular in the developed countries of Europe and are desirable for Ukraine. Manufacturing innovations have a bottom-line cost to set up and maintain, which is difficult for poor countries but desirable over time. Irrational technologies should not be used, as they have reduced economic and environmental performances and are used in poor countries. In this case, it is more expedient to create naturally improved production with minimal human participation, which helps to reduce negative consequences. But due to export targets, many developing countries use old technology or lack of management skills, with a lot of negative impact, to make a lot of money. In this case, it is necessary to introduce European legislation to regulate the quality of life and products. The matrix shows that the worst-case scenario is associated with the cheapening of products using an extensive method, which is no longer used in Europe and poses a threat to the population.

According to the analysis of 10 groups of agricultural goods, the average economic efficiency is 20% less, given the neutralization of waste. However, analyzing environmental consequences of production activities due to the introduction of alternative manufacturing options, the production of most goods in the long-term interval is unprofitable in Ukraine. Calculating the reducing economic efficiency without neutralizing waste at the long-term interval, one takes into account expenses for the neutralization of accumulated waste in the air, soils, purification of water resources, increase in healthcare expenditures, and disability payments as a result of the deterioration of the environmental situation in the region. The analysis takes into account urbanized territories of Ukraine that have a relatively high population density and many enterprises that are directly or indirectly involved. To recover soils in the territories having an indirect impact, sedative plants, soil improvers, and soil revitalizers can be applied based on their chemical composition (Table 3). In areas that have a direct

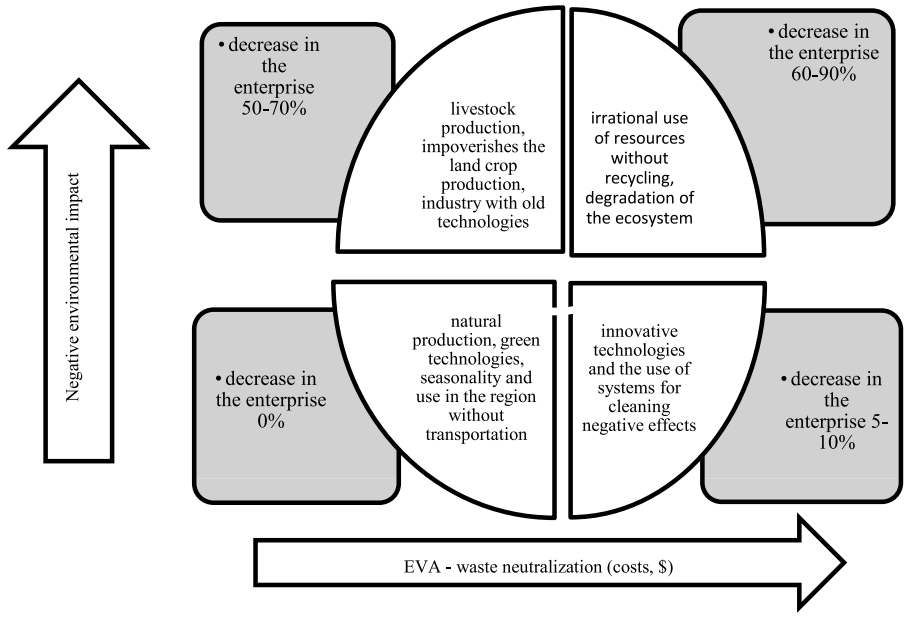

FIGURE 3
Environmental cost matrix.

negative impact on production, complex technologies with waste disposal should be applied based on the principle of production waste–air purification–soil purification–water system purification–biocenosis control.

Table 3 shows that meat products, such as beef, pork, and poultry, have a significant decrease in the economic efficiency because of its no waste neutralization. The cultivation of rice and fruit perennials is environmentally friendly and desirable. The

TABLE 3 Impact of agricultural production on the ecosystem *via* economic efficiency indicators by a group of agricultural products.

Types of agricultural products	Average cost of waste neutralization per 1 ton of the product (USD)	Average cost of indirect impact neutralization per 1 ton of the product at a radius of up to 1 km from production	Selling price in Ukraine per 1 ton of the product (USD)	Decreased profit from sales from the disposal of production waste (USD)	Decrease in economic efficiency without waste neutralization at long-term intervals (%)
Beef (meat)	2,959.00	2,600.00	7,092.40	1,533.40	67.34
First-grade cooked sausages	1,650.00	1,540.00	4,278.90	1,088.90	52.42
Cheese products	1,325.00	1,320.00	4,757.93	2,112.93	37.86
Pork	1,487.00	1,450.00	4,210.71	1,273.71	45.48
Poultry	1,265.00	960.00	2,527.11	302.11	42.28
Rice	554.00	162.00	1,029.32	313.32	9.62
Milk	920.00	711.00	1,001.36	-629.64	37.18
Sunflower oil	1,511.00	470.00	2,100.58	119.58	36.66
Apples	320.00	30.00	438.80	88.80	5.00
White cabbage	280.00	162.00	693.15	251.15	10.07

Calculated by the authors based on State Statistics Service of Ukraine (2021).

decrease in economic efficiency owing to fruit crop production is caused by the use of chemical compounds to improve crop yields and plant care expenses. In case of the neutralization of agricultural waste, the greatest impact is made by farming enterprises engaged in livestock production and crop production enterprises, which impoverish soils or require more fertilizers compared to other crops.

Therefore, the following alternative use of available resources is proposed: creation of an eco-cultural park for public rest and leisure with fruit trees, greenery, and water reservoirs with potential fish breeding, which can generate profit by selling tickets to the territory, providing services, and selling related goods.

A specific feature of the EU Green Deal is the shift to eco-friendly consumption of goods described in the study titled "When emissions turn personal" by Credit Suisse, a Swiss financial conglomerate. Calculations specify consumption standards for an average citizen of Europe, according to the Paris Agreement. In particular, it is recommended to eat 100 g of chicken meat only twice per week (10.4 kg per year) and cheese—25 g once per week (1.3 kg per year). It is recommended to reduce coffee consumption, where greenhouse gas emissions in CO_2 equivalent are 17 kg per 1 kg of the product. In addition, the emphasis is not on restricting human consumption but on plant foods and changing eating habits, which will positively affect human health, reduce costs, and offload the medical system. It is suggested to plant perennial greenery and constantly monitor forests and soils (European Commission, 2020).

As part of the development of projects to establish a standard assessment methodology, the European Commission (2020) posted an initiative for public discussion regarding the environmental footprint of agri-food products. This initiative is relevant in the context of creating a coherent framework for the sustainability of goods, services, and business models to reduce the environmental footprint and contribute to achieving EU climate neutrality (Springmann et al., 2018). The EU is designing a harmonized methodology for comparative calculations of the environmental footprint of the product and sector/industry based on the life cycle, as well as an appropriate legal framework. Coordination results in cost savings for governments and the private sector of countries (because business entities striving for green claims must use two or more methods). It should be noted that the agricultural sector should consider lessons on the functioning of current sustainability tools.

According to the Food and Agriculture Organization (FAO), the food environmental footprint on a global scale is huge; agriculture occupies 40% of land, uses 70% of global water, and generates over 25% of global greenhouse gas emissions. Experts prove that in 2010–2050, as a result of expected changes in the number of inhabitants and income growth, the impact of the food system on the environment could increase by 50–90% and, in the absence of technological changes, it could reach a level beyond the safe existence of humankind (Fairs, (2021).

Taking into account the aforementioned analysis, in addition to the shift to livestock production at specially equipped farms with waste absorption and disposal, decreasing demand for animal products by promoting plant foods, and increasing areas of forests, natural plantations, and other activities, it is crucial to change and control animal feeding to reduce the negative environmental footprint. The feeding coefficient matrix (Gij) (j-parameter in i-group of the food type, coefficients of feeding standards) is the aggregate of foods with admissible deviations (ΔЧ) with regression coefficients (Pij).

$$G_{ij} = \frac{p_{ij\,\Delta x_{oj}}}{\Delta x_j} \geq \sum_{j=1}^{n} A_{ij} X_j, \tag{3}$$

where Ч is the amount of j food in the daily diet and A is the amount of particular nutrients. Taking into account the feeding standards and nutrient content using this model, waste can be minimized. Simultaneously, the second target function can be aimed at minimizing expenses for a certain group of foods.

$$\sum_{i,j=1}^{n} V_{ij} X_{ij} + E_{ij} \rightarrow min. \tag{4}$$

The aforementioned formula illustrates not only decreasing waste in each group of foods but also the decrease in an indirect negative impact, which has a long-term effect and substantial areas of impact. The effect of each type of food should be examined additionally on livestock of particular species to minimize the environmental footprint, taking into account the price characteristics of foods and finding the most appropriate solution for the multi-criteria problem. Currently, this is a relevant issue in state-of-the-art concepts of eco-friendly production.

6.4 Systems for certification and marking of foodstuff sustainability

The Farm-to-Fork strategy stipulates the harmonization of voluntary green claims and the creation of a sustainable marking framework. In addition, methods for calculating the environmental impact are also being improved, and this indicator measures the sustainability of agri-food and food systems. However, the foodstuff market, with voluntary sustainability standards, is still a niche. There are several voluntary certifications of fair trade, which refer to the certification of foodstuff sustainability because they encourage eco-friendly production methods and ethical labor conditions, for example, UTZ certification (trading of coffee, tea products, cocoa, and hazelnut) and RSPO (sustainable production of palm oil), which actively

promote national food sustainability certification programs. For example, the sustainability of the U.S. soybean production pilot program was announced in 2021. Labels of soy products (beverages, candy bars, and protein powders) will contain a sign verifying compliance with the following requirements: cultivated in the United States at family farms with responsible labor practices, meeting ecological standards, and whether heavily eroded soils and marshlands are protected during cultivation. This is also referred to certification and audit of farms required to sell soybeans for biofuel in the European market.

It corresponds to the European Farm-to-Fork strategy stipulating the reducing dependence on critical feed materials, particularly soybeans, cultivated on the degraded land. The biofuel sustainability certification is regulated by Directive 2009/28/EC on the promotion of the use of energy from renewable sources (specified criteria of biofuel sustainability, control over their fulfillment, and calculations of greenhouse gas emissions) and EU Directive 2018/2001 that became effective from 2021, and emission restrictions keep increasing.

Greenhouse gas emissions during agricultural cultivation differ because of their biological features. Leguminous crops accumulate nitrogen in the soil, decreasing greenhouse gas emissions to a particular level. This is one of the reasons why the production of healthy pasta from legumes, such as chickpeas, peas, and lentils, has become increasingly popular. Calculation of the carbon balance, that is, the volume of greenhouse gas emissions during crop cultivation and volume of their deposition by crops, proves that some crops are eventually able to deposit more carbon than forests in the same area. For example, niche crops, such as technical hemp and topinambur, have a strong root system and large biomass, grow fast, require minimum maintenance, do not need agrochemicals, vegetate until frosts, and cover the ground without releasing carbon from soils. According to researchers, a hectare of technical hemp absorbs 8–15 tons of carbon (CO_2) per year, while forests absorb only 2–6 tons depending on the climatic region, type, and age of trees (Fairs, 2021). It is also noted that 1 ha of protective and anti-erosion forests on agricultural lands absorb approximately 7 tons of greenhouse gases per year, which is more than 1 ha of forests on lands of the forest fund (Springmann et al., 2016).

Ukraine exports many carbon-intensive grain crops because they are filled with a large amount of mineral fertilizers, especially nitrogen fertilizers, during cultivation, which results in an overwhelming share of greenhouse gas emissions.

The EU Green Deal's requirement for climate neutrality in Europe as sustainability criterion can lead to a substantial reduction in export of crops for biofuel production from Ukraine because of heavy greenhouse gas emissions throughout their life cycle. Pilot calculations based on data from Ukrainian farming enterprises in 2017 show that greenhouse gas emissions during rapeseed production are quite high in fulfilling the goals of their reduction. Meanwhile, corn production makes the achievement of emission reduction goals problematic (Karwacka et al., 2020).

- Although the list of EU imports subjected to the carbon border adjustment mechanism (CBAM; also known as a cross-border carbon tax/levy initiated and adopted by the EU in the context of economy decarbonization) does not include agricultural food yet, one expects that it can be subjected to CBAM soon because agriculture is one of the dozens of sectors accounting for about 80% of global greenhouse gas emissions (Green et al., 2020; Musa and Basir, 2021).
- The updated nationally determined contribution to the Paris Agreement dated 30 July 2021 is primarily aimed at reducing greenhouse gases by at least 35% (compared to 1990) in order to decrease the accumulation of negative effects from anthropogenic activities, the framework suggesting the implementation until 2030 pays great attention to decarbonization, adoption of green economy, increasing investments in ecological projects, improvement of atmospheric air, and production upgrading using cutting-edge eco-friendly technologies. Thus, Ukraine's legislative framework clearly stipulates a decarbonization vector, which complies with the principles of the EU Green Deal and continues the European integration focus. However, this area requires organizational and economic work for consistent achievement of particular climatic objectives and possibilities of the agricultural sector in the implementation of decarbonization, including those related to agriculture, the growth of organic agriculture, and preservation and enhancement of organic soil substances.
- In addition, it is planned to reduce greenhouse gas emissions as much as possible through the following measures (Ministry of energy and environment protection of Ukraine, 2020): to promote the use of minimum tillage technologies (on an area of 5 million hectares, according to the estimated potential of 17 million hectares, considering certain limitations to the application of these technologies for crops and territories); to promote organic crop production (in an area of 2 million hectare); and to decrease greenhouse gas emissions from livestock farming (specific diets and additives), which leads to a reduction in greenhouse gas emissions; to use nitrogen fertilizers with slow or controlled release of nutrients and apply information technologies in crop production.

Another challenge for national agri-food products for export to the EU is the requirement to comply with tough EU regulations on maximum admissible levels of pesticide and antimicrobial residues. Proper agricultural practice with clear

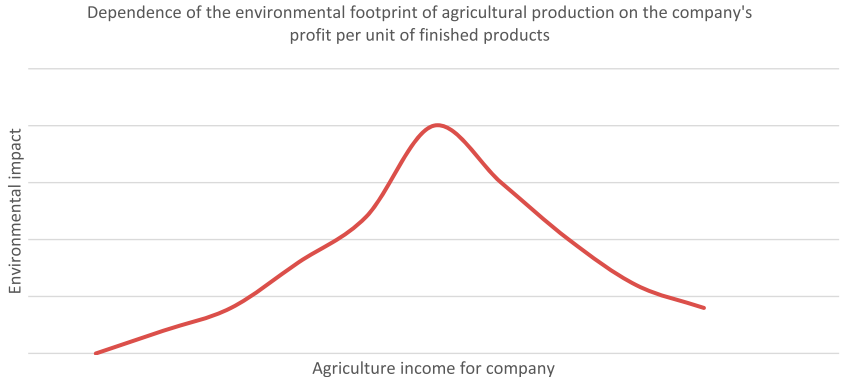

FIGURE 4
Dependence of the environmental footprint of agricultural production on the agriculture company's profit per unit of finished products, 2021.

management principles to obtain safe foodstuffs, which is the basis of regulation in the EU regarding specified contaminants in products, is not common in Ukraine. We should not consider the fact that the average level of using crop protection chemicals in Ukrainian fields is several times lower than that in the EU, as it does not reflect the local pollution of crop products. However, the level of pesticides (1.3 kg/ha according to statistical data, which is twice as low as that in the EU) in the country corresponds to the planned level in the EU until 2030, although their volumes were growing by that time.

The national measures aimed at preventing climate change and proper agricultural practices will have a positive impact on reducing the carbon footprint of agri-food products and improving their sustainability indicators. In areas such as agriculture, land management, and forestry, one expects the largest reduction in greenhouse gas emissions in CO_2 equivalent, according to the afforestation program, ensuring the forest cover at the level of 17% in 2030. Today, the forest cover rate in Ukraine is 15.9%, while the share of forests in the global land fund is 29.4% in Ukraine and 33% in the EU. Taking into account the high agricultural development of Ukrainian territory (69%), high plowing of lands (at the level of 80%), and the significant importance of field protection plantations for farmland security, crop production, and carbon absorption, it is viable to place forest plants on agricultural lands. Exploration of the land allocation mechanism includes degraded and unproductive lands, for afforestation purposes. Therefore, the Decree of the Cabinet of Ministers of Ukraine dated 19 January 2022, No. 70, approves the Concept of the National Target Program for Land Management and Protection that declares to reduce agricultural development and plowing of the territory, preserve protective forest plantations, and take measures to restore them (Cabinet of Ministers of Ukraine, 2022).

It was found that based on the analysis of 50 enterprises of Ukraine and their environmental footprint as a result of agrarian activity, the enterprises that have a higher profit are mostly ecologically safe (Figure 4).

Figure 4 shows that as profits increase at the expansion stage, the amount of waste and negative environmental impact also increases, and when a certain peak is reached, the company can invest in the modernization of production. The need for restoration is caused by the presence of outdated machinery in Ukraine dating back to the Soviet Union, while large agricultural companies are able to buy new machinery and make production eco-friendly, automate it, and monitor its condition. Small businesses in Ukraine do not have enough subsidies and financial resources, so they work with inaccurate technology and use a minimum cost system that does not take into account the environmental impact. In this case, pollution often occurs uncontrollably; therefore, when production expands, there is a moment of changing technologies and the level of automation, which contributes to reducing emissions, improving animal feeding, changing landmarks, and greening.

The hypothesis regarding the reduction of greenhouse gases by improving agar production, adjusting the diet of animals, and changing legislation and norms, which can be reviewed with the example of Europe, is confirmed. It has been established that the automation of production together with the strengthening of environmental regulations will have a positive effect on the environment. It is possible to correct the number of pests with the help of production, and it is possible to reduce the amount of emissions and install modern cleaning systems, which has a long-term positive effect.

7 Conclusion

Food sustainability is a cutting-edge concept among legislators, practitioners, and scientists. Sustainable foodstuffs are gaining content and definition as an economic category. In

Ukraine, there is a problem of increasing environmental impact due to agro-industrial activities, so it is necessary to improve legislation for certain product categories, which will be adapted to European standards, in particular, limiting carbon emissions and hazardous chemicals in production. Thus, it is viable to continue exploring this niche category of products to provide scientific support for their promotion in the market. Agriculture can substantially reduce the carbon and general environmental footprints of agri-food production as characteristics of their sustainability by complying with the requirements of proper agricultural practice, including appropriate storage and use of organic and mineral fertilizers, applying special methods for soil treatment and erosion reduction, decreasing the use of plant protectors, adhering to crop rotations, and advancing feed rations of farm animals.

The developed models and their interpretation in mathematical calculations indicate much greater investment in the development of green technologies in Europe than Ukraine, which remains a depleted resource, so it is desirable to increase investment in green agriculture with the help of European experts and constant monitoring.

The production cost matrix must necessarily reflect the environmental effect, which is different for the types of products and the place of their use. Profits may fall by 90% if irrational use of natural resources is made, which in the long term can lead to global risks, whereas natural production with minimal human involvement is desirable and can be adjusted to reduce negative effects. Then, the profit is saved in the long run. When using innovations, there is a risk of failures and unexplored impacts, which are expensive in the short term but have an improvement effect for a period of more than 10 years, which adjusts the profit by -10%. In developed countries, this path is desirable, while in poor countries, a combination of innovation and natural production is desirable, which helps in symbiosis to create a profitable model of environmental and economic development.

The agri-food sustainability changes stipulated by the EU Green Deal will relate to a much wider range of countries than just EU member states and many exporting countries *via* EU agri-food supply chains. The European Union will internalize the EU Green Deal, promoting the integration of its standards into national policies and economic activities.

The practical advice will be the automation of production and the improvement of technologies that will increase the productivity of agricultural production and reduce the amount of waste, taking into account the experience of Swiss farms.

The European Farm-to-Fork strategy aims to make the food system and European foodstuffs the global standards of sustainable development. The agri-food market is becoming increasingly differentiated based on sustainability of production and supply, as well as related certification and labeling. The mainstreaming of product sustainability in the EU (and other countries) is of concern to third countries due to the additional costs involved. Therefore, whether incoming imports are legal and sustainable (e.g., in terms of decarbonization, avoiding land degradation and deforestation, loss of biodiversity, and respect for workers' rights) will be more strictly controlled, and sustainability requirements will be at the same level as manufacturers' EU.

The declared requirements of the EU Green Deal pose challenges to exports of agri-food and agricultural raw materials to the EU. To prevent EU initiatives from becoming trade barriers to exports, there needs to be a move toward the proper production and supply of sustainable agri-food commodities.

Also, in developed countries, transport costs and logistics chains are minimized, seasonality in the production of agricultural products is taken into account, and they are consumed at the place of their cultivation. This can increase profits by up to 5–10% and minimize the level of environmental impact, which is an alternative for developing countries.

The main aspects of modernization, in addition to changes in production methods, include control and monitoring of the environment, along with an increase in the tax for non-compliance. Local agriculture should diagnose greenhouse gas emissions in technological processes, agriculture, and food chains, as there is no such database.

An innovative focus on carbon-neutral agriculture requires, in addition to the development of the national potential of accounting greenhouse gas emissions, monitoring strategies, economic tools, and the development of appropriate standards and certification schemes. Climate-friendly farming practices will allow farmers to become providers of services of absorbing (removing and sequestering) carbon from the atmosphere and depositing it in soils. This is referred to the development of carbon (regenerative) farming, which is a subject of further research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

All listed authors have made substantial, direct, and intellectual contributions to the study and have approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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