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# MODELLING OF FINANCIAL, ECONOMIC AND LOGISTICS MANAGEMENT IN THE AGRI-FOOD SECTOR OF UKRAINE IN THE CONDITIONS OF GREENING SMART PRODUCTION

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## ABSTRACT

The article examines the features of financial, economic and logistical management in the agri-food sector of Ukraine, taking into account modern trends in ecology and the implementation of smart production. The need to develop integrated assessments for analyzing the state of the industry and its subsystems is substantiated, which allows avoiding a wide range of economic, social and environmental factors. A comprehensive approach to modelling management processes is proposed, which is based on the application of mathematical and statistical methods, in particular multivariate analysis, the principal components method and normalization of indicators. The study has developed a methodology for assessing key aspects of the agri-food sector, which includes determining a set of statistical indicators, their structuring and division into stimulants and de-stimulators, which allows obtaining an objective picture of changes in the industry. It is revealed that the digitalization of management processes plays a key role in ensuring the effectiveness of financial and economic regulation, increased accuracy of analytical data and forecasting the further development of the industry. The introduction of smart technologies allows not only to optimize logistics flows but also to increase the environmental sustainability of agricultural production through the rational use of resources and reducing environmental impact.

The results of the study emphasize the need for further improvement of agri-food management mechanisms, taking into account environmental challenges and global trends in digital transformation. The proposed methodology can be used as a tool for assessing the effectiveness of management decisions, which will contribute to the formation of a balanced strategy for the development of the agro-industrial sector in Ukraine.

**Keywords:** modelling, agri-food sector, agriculture, food industry, sustainable development, smart production, greening, logistics management, financial and economic management

**JEL Classification:** A10, C51, Q10, L60, M11

## INTRODUCTION

The relevance of the topic is due to the need to improve financial, economic and logistical management in the agri-food sector of Ukraine in the context of the greening of smart production. In modern realities, when global environmental challenges, climate change, depletion of natural resources and growing demand for high-quality environmentally friendly products are becoming key factors in the development of the agricultural sector, there is a need to adapt existing business models. The development of smart production in the agri-food sector, based on digital technologies, process automation and the use of artificial intelligence, opens up new opportunities for increasing the efficiency of managing material, financial and information flows. In combination with the principles of ecological production, this contributes to reducing the environmental load, rational use of resources and the creation of sustainable production and logistics systems.

Financial and economic management mechanisms are also undergoing changes in the direction of greater transparency, adaptability and orientation towards environmental criteria. The use of innovative tools, such as green financial engineering, digital platforms for managing financial flows, and blockchain technologies, allows optimizing financial costs and minimizing risks. Thus, a comprehensive approach to modelling financial, economic, and logistical management in the agri-food sector, which takes into account the challenges of greening and digital transformation, is an important condition for ensuring the competitiveness of the industry and its sustainable development in Ukraine.

## LITERATURE REVIEW

A review of the literature indicates the growing attention of researchers to the issues of financial, economic and logistical management in the agri-food sector in the context of digitalization and greening of production. A significant part of scientific works is devoted to the study of strategic resource management, corporate environmental responsibility and the application of innovative technologies in production processes. Some studies focus on the impact of smart technologies on the efficiency of agri-food enterprises, analyze models of digital management and optimise logistics flows. Also relevant is the study of the spatial organization of agroecological clusters and their impact on the sustainable development of regions. Research in the field of financial management focuses on risk assessment, the development of integral indicators for assessing the state of the industry and the use of information systems to automate management decisions. Analysis of scientific sources confirms the need for an integrated approach to modelling financial, economic and logistical management, which allows to an increase in the efficiency of agri-food production, reduces the environmental load and ensures its sustainable development in the context of global changes.

As an example, Lozhachevska et al. (2023) discuss the financial management strategy for marketing and communication design in the context of a smart economy, which directly relates to the concept of economic management and marketing in the agri-food sector of Ukraine, which is also an important part of our article, which considers financial and economic models in the agri-food sector. Gryshchenko et al. (2021) investigate the competitive advantages of educational innovation clusters, which are important for the development of human capital in the agri-food sector, in particular for the training of specialists in the field of financial and logistics management. Panasenko (2024) analyzes the impact of digitalization on the development of the agri-food sector, which is important in the context of using smart technologies to optimize financial and logistics processes. Samofatova (2016) considers the prerequisites and factors of sustainable development of the agri-food sector, which is associated with the need to integrate environmental principles into financial, economic and logistics management. Bakhmat et al. (2022) investigate quality management in education for sustainable development, which emphasizes the importance of human resources for effective management of the agri-food sector in the context of greening.

In the scientific article, Mazur et al. (2021) analyze the improvement of controlling the financial management of enterprises, which is a key aspect for optimizing financial flows in agri-food production. Zoria et al. (2022) consider investment support for the innovative development of agricultural production, which is directly related to financial management in the context of greening. Gmyrya (2019) investigates food security as a key factor of economic development, which is associated with the need for effective logistical and financial management in the agri-food sector. Kubitskyi et al. (2024) assess the impact of innovative technologies on global competitiveness through modelling, which is important for developing effective management decisions in the financial and economic sphere of agri-food. Kopishynska et al. (2024) study the management of agroecosystem productivity based on specialized information systems, which is related to the digitalization of management processes in the field of logistics and finance. Kyryliuk et al. (2021) analyze the economic and organizational factors of ensuring the quality of livestock products, which affects management decisions in the financial, economic and logistical spheres of agri-food production.

Balanovska et al. (2022) analyze the features of the development of agricultural entrepreneurship in Ukraine, which is related to financial and economic management in the agri-food sector and the introduction of innovative approaches to logistics processes. Krylov et al. (2023) investigate the problems of ensuring food security in Ukraine, which is directly related to the effective management of financial flows and logistics infrastructure in the face of global challenges. Kuchechuk (2022) examines global food security trends, which is an important aspect of forming a strategy for sustainable development of the agri-food sector of Ukraine in the context of greening. Kasych et al. (2020) examine corporate environmental responsibility in the context of strategic management, which is important for integrating environmental standards into the financial and economic models of the agri-food sector. Kyryliuk et al. (2021) analyze economic and organizational factors in ensuring the safety and quality of livestock products, which affects financial decisions and logistical approaches in the agri-food sector.

Scientists Hryhoruk and Makarov (2018) conduct an integral assessment of the level and dynamics of the agrarian potential of regions, which is the basis for making effective management decisions in financial and economic planning. Khodakivska et al. (2022) investigate the modelling of the management of economic security of innovative entrepreneurship, which is important for developing strategies for the development of agri-food enterprises in modern conditions. Hryhorenko et al. (2017) assess the regional features of the agrarian potential of Ukraine, which is important for ensuring economic security and effective distribution of financial resources. Kubitskyi et al. (2023) analyze the management of higher education institutions as a development tool, which is important for training personnel in the field of financial and economic management of agri-food production.

Particular attention is paid to the works of Hryhoruk (2012) who investigates the methodological principles of constructing an integral indicator, which is important for assessing the effectiveness of financial and economic management in the agri-food sector. Hryhoruk (2015) proposes an approach to an integrated assessment of the innovative potential of processing industry enterprises, which is important for strategic financial management and greening of production.

The Importance of Labour, Kyryliuk et al. (2021), where the authors analyze the organizational and economic factors of ensuring the safety and improving the quality of livestock products, which is directly related to financial and economic management in the field of agri-food production. Komelina and Panasenko (2013) consider the information and methodological support for managing the development of the agricultural sector, which is important for improving logistical and financial processes in modern conditions. Oseredchuk et al. (2022) explore new approaches to monitoring the quality of education, which is important for training personnel in the field of financial, economic and logistical management of the agri-food sector. Navrotskyi and Palyukh (2015) assess the effectiveness of the development of the agricultural sector of Ukraine, taking into account state funding, which is directly related to financial and economic management in the industry. Zhyvko et al. (2022) analyze the issues of digitalization security in management accounting and finance, which is relevant for the implementation of smart technologies in the financial and economic management of agri-food enterprises. Plaskon et al. (2016) use mathematical modelling to analyze the functioning of agricultural formations, which can be used to develop financial and economic models in the field of agri-food production. Babenko (2017) investigates factors affecting the innovative activity of agricultural enterprises, which is a key aspect of financial management and logistics development in the agricultural sector. Voznyuk et al. (2021) analyze interdisciplinary educational technologies, which is important for training specialists in the field of digital solutions for agri-food production. Sokil et al. (2018) assess the sustainable development of Ukrainian agriculture, which is important for the development of environmentally oriented financial and economic models. Britz et al. (2012) consider the tools of integrated assessment in agriculture, which is important for improving financial and economic management in the agri-food sector. Ishchejkin et al. (2022) consider the information subsystem of agri-food enterprise management in the context of digitalization, which is directly correlated with our study, which also covers aspects of technologies and digital platforms for managing the agricultural sector in the context of greening and smart production. Vasylchak et al. (2022) analyze state regulation of employment in the context of innovative development of entrepreneurship, which affects financial and logistical decisions in the agri-food sector. Gabbert et al. (2010) investigate the analysis of uncertainty in integrated assessment, which is important for the development of management models in the agri-food sector. Ovcharenko et al. (2022) study spatial management and modelling of eco-clusters, which is relevant to the ecological development of the agri-food sector. Li et al. (2012) considers the modelling of eco-agricultural systems, which is relevant for the development of ecologically oriented financial and economic strategies in the agricultural sector.

Kotir et al. (2016) analyze the systemic dynamics of water resources management and agricultural development, which is important for sustainable financial and economic management in the agri-food sector. Stolyarov et al. (2022) investigate the optimization of material and technical supply of industrial enterprises, which is important for improving logistics in the agri-food sector. Pavlov (2014) analyzes the agri-food sector of Ukraine as an object of national security, which is associated with effective financial and economic management in the industry. The study of Chyzhevska et al. (2022) concerns the assessment and modelling of the efficiency of economic processes in the context of human capital development and interstate development. Our study can interact with this topic, since the growth of human capital is an important aspect for effective management in the agri-food sector, especially in the context of digitalization and smart production. The State Statistics Service of Ukraine (2024) provides up-to-date statistical data that serve as the basis for the analysis of financial, economic and logistical management of the agri-food sector.

The main shortcomings of existing scientific research in the field of modelling financial, economic and logistical management in the agri-food sector of Ukraine are the fragmentation of approaches and insufficient integration of environmental aspects into financial and logistical models. Many works focus on individual aspects - economic efficiency, digital technologies or environmental sustainability - without a comprehensive analysis of their interrelationships.


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There is also a lack of research that takes into account the specifics of the Ukrainian agrarian sector, especially in the context of crisis phenomena and transformational changes in the global economy. Existing models are often theoretical in nature and are not always adapted to practical application at the enterprise level.

A separate drawback is the lack of attention to modern digital technologies in logistics, in particular artificial intelligence and big data, which can significantly improve management processes. The literature also lacks detailed research on the interaction of environmental clusters with financial mechanisms for stimulating sustainable development. The listed shortcomings indicate the need for further research aimed at creating integrated models that take into account financial, environmental and technological factors, as well as their adaptation to the realities of the Ukrainian agri-food sector.

## AIMS AND OBJECTIVES

The purpose of the article is to develop and improve methodological approaches to modelling financial, economic and logistical management in the agri-food sector of Ukraine in the context of greening smart production. The research is aimed at forming integral assessments of the state of the industry and its subsystems, which will allow to substantiate effective management decisions to increase the sustainability, competitiveness and environmental balance of agri-food production.

The objectives of the article are:

- to conduct an analysis of factors affecting the financial and economic state and logistical management in the agri-food sector of Ukraine;
- to determine approaches to assessing the integral indicators of the state of the industry and its main subsystems;
- to develop a methodology for normalizing statistical indicators to ensure correct integral assessment;
- to justify the use of the principal components method to determine the weighting coefficients of integral assessments;
- to analyze the dynamics of the state of the agri-food sector of Ukraine using the calculated integral assessments;
- to propose ways to improve management decisions in the field of finance, economics and logistics of agri-food production, taking into account environmental challenges and digital technologies.

## METHODS

The study used a comprehensive methodological approach, including mathematical and statistical methods of analysis, methods of multivariate statistics, in particular the principal component method, and methods of normalization of indicators.

To assess the impact of various factors on the agri-food sector, integral estimates of the state of this sector and its subsystems were calculated. These estimates are formed on the basis of statistical indicators, which are divided into stimulants and de-stimulators. To ensure comparability of the data, their normalization was carried out using dimensionless indicators in the range from 0 to 1.

The linear convolution method was used to calculate integral estimates of each group of indicators, where the weight coefficients were determined by the modified principal component method. The determination of these coefficients is based on the calculation of the covariance matrix between indicators and finding the eigenvector corresponding to the maximum eigenvalue.

This approach allows us to take into account the relationships between indicators and ensures the objectivity and reliability of integral assessments used to make effective management decisions in the field of agri-food production and logistics. The development of the agri-food sector is influenced by many different factors. To make effective management decisions in this industry, it is necessary to assess the impact of such factors on both the agri-food sector as a whole and its individual subsystems (agriculture, agricultural raw material processing industry, food trade, logistics, social development of rural areas, environmental protection and preservation). Such an assessment requires determining integral assessments of the state of the agri-food sector and its subsystems. These assessments are created on the basis of statistical information and play the role of criteria when choosing options for management decisions. To develop integral assessments, we select primary statistical indicators that characterize various aspects of activity in the agri-food sector and group them according to the structure of this sector.

Let us denote the set of selected indicators by Q. This set consists of the following subsets: Q1 – production volumes of crop products, Q2 – production volumes of livestock products, Q3 – cost of agricultural products, Q4 – cost of sold products of the food industry, Q5 – value of wholesale turnover of food products, Q6 – indicators of retail sales of food products, Q7 – volume of food exports, Q8 – logistics indicators, Q9 – indicators of social development of rural areas, Q10 – indicators of environmental protection and preservation. Let $Q_i = \{q_i^j\}_{j=1}^{n_i}$.

Subset Q1 includes indicators of production volumes (in thousand tons) of grain and leguminous crops ($q_1^1$), industrial sugar beet ($q_1^2$), sunflower ($q_1^3$), potatoes ($q_1^4$), vegetable crops ($q_1^5$), fruit and berry crops ($q_1^6$). Subset Q2 includes indicators of production volumes (in thousand tons) of beef and veal ($q_2^1$), pork ($q_2^2$), poultry ($q_2^3$), lamb and goat meat ($q_2^4$), rabbit meat ($q_2^5$), milk ($q_2^6$), eggs in million pieces ($q_2^7$), honey in tons ($q_2^8$). In the subset Q3 we include the cost price indicators (in UAH/t) of grain and legume crops ($q_3^1$), sunflower seeds ($q_3^2$), industrial sugar beet ($q_3^3$), potatoes ($q_3^4$), vegetable crops ($q_3^5$), fruit crops ($q_3^6$), berry crops ($q_3^7$), raw milk ($q_3^8$), eggs in UAH/thousand pcs. ($q_3^9$), honey in UAH/kg ($q_3^{10}$). The subset Q4 includes indicators of the cost of sold food products (in UAH thousand): meat and meat products ($q_4^1$), processed and preserved fruits and vegetables ($q_4^2$), oil and animal fats ($q_4^3$), dairy products ($q_4^4$), products of the flour and cereal industry, starch and starch products ($q_4^5$), bread, bakery and flour products ($q_4^6$).

The subset Q5 includes indicators of wholesale turnover (in UAH thousand) of meat and meat products ($q_5^1$), dairy products, butter and cheeses ($q_5^2$), eggs ($q_5^3$), oil and edible fats ($q_5^4$), bakery and confectionery flour products ($q_5^5$), sugar ($q_5^6$), rice ($q_5^7$), flour ($q_5^8$), cereals ($q_5^9$), pasta ($q_5^{10}$), processed fruits and vegetables ($q_5^{11}$), fresh fruits and vegetables ($q_5^{12}$). The subset Q6 includes indicators of retail sales volumes (in quintals) of fresh and frozen meat and poultry ($q_6^1$), smoked and salted meat and sausage products ($q_6^2$), rennet, processed and fermented milk cheese ($q_6^3$) butter ($q_6^4$), eggs in thousand pieces ($q_6^5$), vegetable oil ($q_6^6$), sugar ($q_6^7$), bakery products except confectionery ($q_6^8$), flour confectionery products ($q_6^9$), sugar confectionery products and ice cream ($q_6^{10}$), flour ($q_6^{11}$), cereals ($q_6^{12}$), pasta ($q_6^{13}$), fresh vegetables ($q_6^{14}$), fresh fruits, berries, grapes and nuts ($q_6^{15}$), processed vegetables and fruits ($q_6^{16}$). The subset Q7 includes export indicators (in USD thousands) of meat ($q_7^1$), milk, dairy products, eggs and honey ($q_7^2$), other products of animal origin ($q_7^3$), vegetables ($q_7^4$), edible fruits and nuts ($q_7^5$), products of the flour and cereal industry ($q_7^6$), seeds and fruits of oil plants ($q_7^7$), fats and oils of animal or vegetable origin ($q_7^8$), meat and fish products ($q_7^9$), sugar and sugar confectionery ($q_7^{10}$), finished grain products ($q_7^{11}$), processed vegetable products ($q_7^{12}$), various food products ($q_7^{13}$).

Subset Q8 includes indicators of domestic transportation of agricultural products by road, thousand tons ($q_8^1$), international transportation of agricultural products by road, thousand tons ($q_8^2$), domestic transportation of food products by road, thousand tons ($q_8^3$), international transportation of food products by road, thousand tons ($q_8^4$), rail transportation of grain and milled products, million tons ($q_8^5$). Subset Q9 includes indicators of the number of registered unemployed among the rural population, thousand people ($q_9^1$), the number of economically active population in rural areas, thousand people ($q_9^2$), the average monthly salary of full-time employees in agriculture in 2013 prices, UAH ($q_9^3$), the number of students in full-time rural secondary education institutions, persons ($q_9^4$), the percentage of the rural population who, according to the survey results, assessed their health as good ($q_9^5$), the percentage of the rural population who, according to the survey results, assessed their health as bad ($q_9^6$). The subset Q10 includes indicators of pollutant emissions in agriculture, thousand tons ($q_{10}^1$), carbon dioxide emissions in agriculture, thousand tons ($q_{10}^2$), capital investments in environmental protection in agriculture in actual prices, UAH thousand ($q_{10}^3$), current expenditures on environmental protection in agriculture in actual prices, UAH thousand ($q_{10}^4$), pollutant emissions in the food industry, thousand t ($q_{10}^5$), carbon dioxide emissions in the food industry, thousand t ($q_{10}^6$), capital investments in environmental protection in the food industry in actual prices, UAH thousand ($q_{10}^7$), current expenses for environmental protection in the food industry in actual prices, UAH thousand ($q_{10}^8$).

The information basis for forming integral assessments of the state of the agri-food sector as a whole and its components is the set of values of indicators $q_i^j$ for the retrospective period, which includes 2014-2021 (before the start of the full-scale Russian invasion). The value of the indicator $q_i^j$ in the t-th year of the retrospective period will be denoted by $q_i^j(t)$. These values make it possible to identify existing correlations between these indicators and use the information obtained to determine the coefficients included in the integral assessments.

Indicators from the set Q are divided into stimulants and de-stimulators. An increase in the values of stimulants corresponds to an improvement in the state of the agri-food sector and increases its integral assessment, while an increase in the values of de-stimulators, on the contrary, reduces this assessment. De-stimulators are indicators $q_9^1$, $q_9^6$, $q_{10}^1$, $q_{10}^2$, $q_{10}^5$, $q_{10}^6$ and all indicators of group Q3. All other indicators from the set Q are stimulants.


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The use of indicators from the set Q when calculating integral estimates requires their transformation into dimensionless stimulators with a range of variation from 0 to 1. For stimulator indicators, this can be done using the following transformation

$$h_i^j(t) = \frac{q_i^j(t) - \min_t q_i^j(t)}{\max_t q_i^j(t) - \min_t q_i^j(t)} \quad (1)$$

For destimulator indicators, we use the transformation defined by the equality

$$h_i^j(t) = \frac{\max_t q_i^j(t) - q_i^j(t)}{\max_t q_i^j(t) - \min_t q_i^j(t)} \quad (2)$$

Thus, if the indicator $q_i^j$ is a stimulator, then as it increases, the corresponding indicator $h_i^j$. If the indicator $q_i^j$ is a destimulator, then when it increases, the corresponding indicator $h_i^j$ decreases.

For each group of indicators Qi, we define the integral estimate $W_i$ as a linear combination of indicators $h_i^j$ with weight coefficients $\beta_i^j$, that is, the equality holds:

$$W_i(t) = \sum_{j=1}^{n_i} \beta_i^j h_i^j(t) \quad (3)$$

We determine the weight coefficients $\beta_i^j$ by the modified principal component method. To do this, we find the matrix $L_i$, the elements of which are the covariance coefficients between the indicators $h_i^j$, and determine the eigenvector of this matrix, which corresponds to its maximum eigenvalue. We choose the coefficients $\beta_i^j$ proportional to the squares of the components of this vector.

## RESULTS

According to the chosen methodology, we will calculate the efficiency of financial, economic and logistical management in the agri-food sector of Ukraine in the conditions of greening smart production. The values of indicators [42] included in the set Q1 and determining the integral assessment of crop production are given in Table 1.

**Table 1. Values of indicators reflecting the volumes of crop production.**

| Year | t | $q_1^1$ | $q_1^2$ | $q_1^3$ | $q_1^4$ | $q_1^5$ | $q_1^6$ |
|---|---|---|---|---|---|---|---|
| 2014 | 1 | 63859.3 | 15734.1 | 10133.8 | 23693.4 | 9637.5 | 1999,1 |
| 2015 | 2 | 60125.8 | 10330.8 | 11181.1 | 20839.3 | 9214 | 2152,8 |
| 2016 | 3 | 66088 | 14011.3 | 13626.9 | 21750.3 | 9414.5 | 2007,3 |
| 2017 | 4 | 61916.7 | 14881.6 | 12235.5 | 22208.2 | 9286.3 | 2048 |
| 2018 | 5 | 70056.5 | 13967.7 | 14165.2 | 22504 | 9440.2 | 2571,3 |
| 2019 | 6 | 75143.2 | 10204.5 | 15254.1 | 20269.2 | 9687.6 | 2118,9 |
| 2020 | 7 | 64933.4 | 9150.2 | 13110.4 | 20838 | 9652.8 | 2023,9 |
| 2021 | 8 | 86010 | 10854 | 16392 | 21356 | 9935 | 2235 |
| Maximum value | | 86010 | 15734.1 | 16392 | 23693.4 | 9935 | 2571.3 |
| Minimum value | | 60125,8 | 9150.2 | 10133.8 | 20269.2 | 9214 | 1999.1 |
| Difference between maximum and minimum value | | 25884,2 | 6583.9 | 6258.2 | 3424.2 | 721 | 572.2 |

The values of the corresponding normalized indices $h_1^j$ are shown in Table 2.

**Table 2. Values of normalized indices $h_1^j$ for integral evaluation.**

| Year | t | $h_1^1$ | $h_1^2$ | $h_1^3$ | $h_1^4$ | $h_1^5$ | $h_1^6$ |
|---|---|---|---|---|---|---|---|
| 2014 | 1 | 0.00000 | 0.23034 | 0.06919 | 0.38366 | 0.58018 | 0.18573 |
| 2015 | 2 | 0.17932 | 0.73833 | 0.87052 | 0.73171 | 0.16013 | 0.00000 |
| 2016 | 3 | 0.16735 | 0.55816 | 0.33583 | 0.64418 | 0.81817 | 0.47563 |
| 2017 | 4 | 0.16649 | 0.43254 | 0.56626 | 0.65265 | 0.00000 | 0.16611 |
| 2018 | 5 | 0.00000 | 0.27809 | 0.10028 | 0.31373 | 0.65687 | 0.60860 |
| 2019 | 6 | 0.26861 | 0.01433 | 0.08546 | 1.00000 | 0.20937 | 0.04334 |
| 2020 | 7 | 0.00000 | 0.23034 | 0.06919 | 0.38366 | 0.58018 | 0.18573 |
| 2021 | 8 | 0.17932 | 0.73833 | 0.87052 | 0.73171 | 0.16013 | 0.00000 |

The matrix $L_1$ for the indices $h_1^j$ is as follows:

$$\begin{pmatrix} 0,0945 & -0,0337 & 0,0832 & -0,0236 & 0,0776 & 0,0344 \\ -0,0337 & 0,1280 & -0,0467 & 0,0970 & -0,0340 & 0,0005 \\ 0,0832 & -0,0467 & 0,0955 & -0,0468 & 0,0557 & 0,0392 \\ -0,0236 & 0,0970 & -0,0468 & 0,0909 & -0,0094 & 0,0064 \\ 0,0776 & -0,0340 & 0,0557 & -0,0094 & 0,0952 & 0,0002 \\ 0,0344 & 0,0005 & 0,0392 & 0,0064 & 0,0002 & 0,0973 \end{pmatrix}$$

The maximum eigenvalue of this matrix $\lambda_1^{max} = 0,3117$, corresponding to the eigenvector

P1=$\{0,465; -0,4796;\ 0,4906;\ 0,3764;\ 0,3848;\ 0,1524\}$.

Therefore, the weight coefficients of the integral assessment of crop production are as follows: $\beta_{11}$ = 0.2162, $\beta_{12}$ = 0.2300, $\beta_{13}$ = 0.2407, $\beta_{14}$ = 0.1417, $\beta_{15}$ = 0.1481, $\beta_{16}$ = 0.0232. Thus, the integral estimate $W_1$ has the form:

$W_1$(t) = 0,216$h_1^1$(t) + 0,230$h_1^2$(t) + 0,241$h_1^3$(t) + 0,1417$h_1^4$(t) + 0,148$h_1^5$(t) + + 0,023$h_1^6$(t).

Similarly, we determine the integral estimates $W_i$ of other components of the agri-food sector, corresponding to the groups of indicators $Q_i$. The equations that determine these estimates are as follows:

*for livestock production:*

$W_2$(t) = 0,1255$h_2^1$(t) + 0,1094$h_2^2$(t) + 0,2472$h_2^3$(t) + 0,1153$h_2^4$(t) + 0,1155$h_2^5$(t) + + 0,1697$h_2^6$(t) + 0,0563$h_2^7$(t) + 0,0613$h_2^8$(t);

*for the cost of agricultural products:*

$W_3$(t) = 0,0981$h_3^1$(t) + 0,0955$h_3^2$(t) + 0,083$h_3^3$(t) + 0,0968$h_3^4$(t) + 0,0864$h_3^5$(t) + +0,085$h_3^6$(t) + 0,1349$h_3^7$(t) + 0,1089$h_3^8$(t) + 0,08$h_3^9$(t)+ 0,131$h_3^{10}$(t);

*for the cost of sales of food industry products:*

$W_4$(t) = 0,2130$h_4^1$(t) + 0,1096$h_4^2$(t) + 0,1669$h_4^3$(t) + 0,2403$h_4^4$(t) + 0,1323$h_4^5$(t) + +0,1379$h_4^6$(t);

*for the wholesale trade of food products:*

$W_5$(t) = 0,1427$h_5^1$(t) + 0,1123$h_5^2$(t) + 0,1112$h_5^3$(t) + 0,0257$h_5^4$(t) + 0,1314$h_5^5$(t)+ 0,0245$h_5^6$(t) + 0,0657$h_5^7$(t) + 0,0103$h_5^8$(t) + 0,0128$h_5^9$(t) + 0,0767$h_5^{10}$(t) + + 0,1455$h_5^{11}$(t) + 0,141$h_5^{12}$(t);


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*for the retail sale of food products:*

$W_6(t) = 0{,}0396h_6^1(t) + 0{,}1275h_6^2(t) + 0{,}1317h_6^3(t) + 0{,}0045h_6^4(t) + 0{,}0509h_6^5(t) + +0{,}0018h_6^6(t) + 0{,}0047h_6^7(t) + 0{,}000022h_6^8(t) + 0{,}0408h_6^9(t) + 0{,}1327h_6^{10}(t) + +0{,}0099h_6^{11}(t) + 0{,}0036h_6^{12}(t) + 0{,}0830h_6^{13}(t) + 0{,}1006h_6^{14}(t) + 0{,}0{,}0899h_6^{15}(t) + +0{,}1788h_6^{16}(t)$;

*for food exports:*

$W_7(t) = 0{,}1861h_7^1(t) + 0{,}0046h_7^2(t) + 0{,}0417h_7^3(t) + 0{,}05h_7^4(t) + 0{,}1562h_7^5(t) + +0{,}0368h_7^6(t) + 0{,}1564h_7^7(t) + 0{,}1208h_7^8(t) + 0{,}0965h_7^9(t) + 0{,}0026h_7^{10}(t) + +0{,}0849h_7^{11}(t) + 0{,}0076h_7^{12}(t) + 0{,}0559h_7^{13}(t)$;

*for logistics indicators:*

$W_8(t) = 0{,}2415h_8^1(t) + 0{,}1042h_8^2(t) + 0{,}2193h_8^3(t) + 0{,}2668h_8^4(t) + 0{,}1683h_8^5(t)$;

*for indicators of social development in rural areas:*

$W_9(t) = 0{,}0111h_9^1(t) + 0{,}0035h_9^2(t) + 0{,}3037h_9^3(t) + 0{,}0257h_9^5(t) + 0{,}3979h_9^5(t) + +0{,}2582h_9^6(t)$;

*for environmental protection and conservation indicators:*

$W_{10}(t) = 0{,}1142h_{10}^1(t) + 0{,}1030h_{10}^2(t) + 0{,}0407h_{10}^3(t) + 0{,}1733h_{10}^4(t) + 0{,}1385h_{10}^5(t) + +0{,}0795h_{10}^6(t) + 0{,}1848h_{10}^7(t) + 0{,}1661h_{10}^8(t)$.

The complex integral estimate W of the integral estimate of the state of financial, economic and logistical management in the agri-food sector of Ukraine is defined as a linear combination of the obtained integral estimates $W_i$, i.e., it has the form

$$W(t) = \sum_{i=1}^{10} \gamma_i W_i(t), \quad (4)$$

*where the weight coefficients $\gamma_i$ are determined by the modified principal component method.*

The covariance coefficients between the integral estimates $W_i$ are determined based on the values of these estimates during 2014-2021. The covariance matrix, the elements of which are these covariance coefficients, has the form:

$$\begin{pmatrix}
0{,}0296 & 0{,}0061 & -0{,}0209 & 0{,}0252 & 0{,}0211 & 0{,}0194 & 0{,}0293 & 0{,}0111 & -0{,}0112 & 0{,}0017 \\
0{,}0061 & 0{,}0057 & -0{,}0073 & 0{,}0068 & 0{,}0131 & 0{,}0154 & 0{,}0135 & 0{,}0061 & 0{,}0019 & 0{,}0030 \\
-0{,}0209 & -0{,}0073 & 0{,}1024 & -0{,}0924 & -0{,}0880 & -0{,}0751 & -0{,}0662 & -0{,}0826 & 0{,}0242 & -0{,}0223 \\
0{,}0252 & 0{,}0068 & -0{,}0924 & 0{,}0879 & 0{,}0745 & 0{,}0618 & 0{,}0647 & 0{,}0756 & -0{,}0268 & 0{,}0159 \\
0{,}0211 & 0{,}0131 & -0{,}0880 & 0{,}0745 & 0{,}0973 & 0{,}0845 & 0{,}0621 & 0{,}0683 & -0{,}0147 & 0{,}0266 \\
0{,}0194 & 0{,}0154 & -0{,}0751 & 0{,}0618 & 0{,}0845 & 0{,}0881 & 0{,}0623 & 0{,}0605 & -0{,}0011 & 0{,}0242 \\
0{,}0293 & 0{,}0135 & -0{,}0662 & 0{,}0647 & 0{,}0621 & 0{,}0623 & 0{,}0649 & 0{,}0540 & -0{,}0118 & 0{,}0115 \\
0{,}0111 & 0{,}0061 & -0{,}0826 & 0{,}0756 & 0{,}0683 & 0{,}0605 & 0{,}0540 & 0{,}0900 & -0{,}0228 & 0{,}0168 \\
-0{,}0112 & 0{,}0019 & 0{,}0242 & -0{,}0268 & -0{,}0147 & -0{,}0011 & -0{,}0118 & -0{,}0228 & 0{,}0206 & -0{,}0017 \\
0{,}0017 & 0{,}0030 & -0{,}0223 & 0{,}0159 & 0{,}0266 & 0{,}0242 & 0{,}0115 & 0{,}0168 & -0{,}0017 & 0{,}0101
\end{pmatrix}$$

The maximum eigenvalue of this matrix $\lambda=0.4668$. It corresponds to the eigenvector

P={0.1187; 0.0549; -0.4544; 0.4108; 0.4258; 0.3838; 0.3342; 0.3835; -0.0958; 0.1053}. The weighting factors $\gamma\_i$ are proportional to the squares of the components of this vector. Therefore, the integral assessment of the state of the agri-food sector of Ukraine is calculated by the formula:

$$W(t) = 0{,}0141W_1(t) + 0{,}0030W_2(t) + 0{,}2065W_3(t) + 0{,}1688W_4(t) + 0{,}1813W_5(t) + 0{,}1473W_6(t) + 0{,}1117W_7(t) + 0{,}1471W_8(t) + 0{,}0092W_9(t) + 0{,}0111W_{10}(t).$$

The value of this integral assessment and its components Wi in 2014-2021 are given in Table 3.

**Table 3. The value of the integral assessment of the state of financial, economic and logistical management in the agri-food sector of Ukraine in the conditions of greening smart production and the components of this assessment.**

| Integral assessments | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|
| Volumes of crop production | 0.4899 | 0.1114 | 0.4568 | 0.3931 | 0.5685 | 0.4613 | 0.2693 | 0.7191 |
| Volumes of livestock production | 0.4885 | 0.3834 | 0.3180 | 0.3321 | 0.3556 | 0.4650 | 0.3946 | 0.5426 |
| Cost of agricultural products | 0.9966 | 0.8133 | 0.6868 | 0.5578 | 0.4287 | 0.2996 | 0.1232 | 0 |
| Cost of sold products of the food industry | 0 | 0.1379 | 0.2566 | 0.5036 | 0.5890 | 0.6697 | 0.6665 | 0.9525 |
| Wholesale turnover of food products | 0.1689 | 0.2302 | 0.2735 | 0.0266 | 0.5003 | 0.6656 | 0.8069 | 0.9640 |
| Retail sale of food products | 0.3936 | 0.1005 | 0.1624 | 0.1207 | 0.3153 | 0.6227 | 0.8592 | 0.8699 |
| Export of food products | 0.3244 | 0.0737 | 0.0740 | 0.3736 | 0.4493 | 0.6027 | 0.4921 | 0.8994 |
| Logistics indicators | 0 | 0.1617 | 0.2333 | 0.4354 | 0.4051 | 0.9721 | 0.7114 | 0.6603 |
| Indicators of social development of rural areas | 0.7203 | 0.5233 | 0.3297 | 0.4054 | 0.3018 | 0.3077 | 0.5616 | 0.3182 |
| Indicators of environmental protection and preservation | 0.3423 | 0.3811 | 0.4566 | 0.2744 | 0.3372 | 0.4618 | 0.5828 | 0.5450 |
| Complex integral assessment | 0.3494 | 0.2915 | 0.3167 | 0.3418 | 0.4504 | 0.6134 | 0.5870 | 0.6820 |

The dynamics of a comprehensive integrated assessment of the state of financial, economic and logistical management in the agri-food sector of Ukraine in the context of greening smart production is shown in Figure 1.

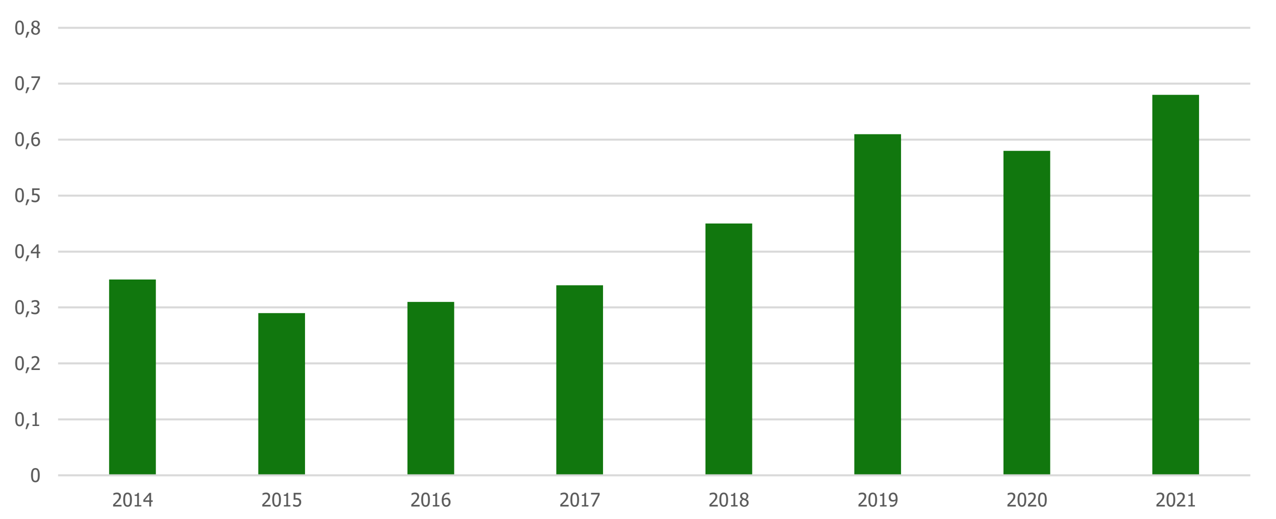


**Figure 1. Dynamics of the comprehensive integrated assessment of the state of financial, economic and logistical management in the agri-food sector of Ukraine.**

The conducted study shows that the integrated assessment of the state of financial, economic and logistical management in the agri-food sector of Ukraine in the context of the greening of smart production in 2015 decreased by 16.6% compared to the previous year. The main factors that influenced the decrease in this assessment were significant decreases in the integrated assessments of the production volumes of crop production (by 77.3%), retail sales of food products (by 74.5%) and exports of food products (by 77.3%). At the same time, the assessments of the indicators of wholesale turnover of food products and indicators of environmental protection and preservation increased slightly (by 36.3% and 11.3%, respectively). From 2015 to 2019, there has been an increase in the comprehensive integral state of financial, economic and logistical management in the agri-food sector of Ukraine in the context of the greening of smart production, although the level of 2014 was exceeded only in 2018. The highest growth rate, equal to 36.2% compared to the previous year, was observed in 2019. The main factors of this growth were the improvement of the assessment of retail sales of food products and logistics indicators (by 97.5% and 140%, respectively). In 2020, there was a slight decrease in the comprehensive integral assessment, primarily due to a decrease in the integrated assessment of crop production. In 2021, the integrated assessment of the state of the agri-food sector of Ukraine increased, exceeding the assessment for 2019 by 16.2%. One


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of the most complex complex processes that ensure the development of society is digitalization. The introduction of digitalization in the agri-food sector will make it possible to obtain timely up-to-date values of indicators, guarantee their accuracy and long-term storage. The rapid introduction of digital technologies in the agri-food sector of Ukraine requires government officials to have the appropriate tools that will ensure the processes of making effective management decisions regarding the formation of a digital economy and the digitalization of the agri-food market.

The results of the study confirm the importance of a comprehensive approach to assessing the state of financial, economic and logistical management in the agri-food sector of Ukraine in the context of the greening of smart production. The proposed methodology based on integral assessments allows for an objective analysis of the dynamics of the development of the industry, taking into account a wide range of economic, social and environmental factors. The use of mathematical and statistical methods and normalization of indicators helps to increase the accuracy and informativeness of the results obtained.

The analysis shows the dynamics of changes in the financial, economic and logistical management of the agri-food sector of Ukraine in the context of the greening of smart production during 2014–2021. The general trend indicates significant fluctuations in indicators in different years, which reflects the impact of economic, technological and environmental factors on the industry.

At the initial stage (2014–2015), there is a significant decrease in most integral estimates, which is likely due to macroeconomic instability, a decrease in the volume of production and exports of food products. Since 2016, there has been a gradual recovery of some indicators, in particular, the cost of sales of food industry products, wholesale turnover and logistics parameters.

The estimate of the cost of agricultural products demonstrates a steady decrease, which may indicate an improvement in production efficiency or a decrease in profitability due to increased costs. At the same time, the cost of sales of food industry products and the level of logistics indicators after 2017 began to grow significantly, which may indicate the intensification of market processes and improvement of the supply infrastructure.

The most dynamic period is after 2018 when almost all indicators show growth. The positive trend in food retail, exports and logistics is particularly noticeable, which may indicate the industry's adaptation to new economic conditions, the introduction of digital technologies and increased management efficiency. The overall comprehensive integral assessment reached its peak in 2021, indicating an improvement in the overall condition of the agri-food sector. This may be due to innovative changes in financial, economic and logistical management, increased exports and more active use of environmental approaches in production. The results obtained emphasize the need for further digitalization of the agri-food sector, which will allow to increase the efficiency of management decisions, reduce risks and adapt to modern challenges. The introduction of digital technologies, automated data analysis systems and the expansion of environmental standards will contribute to the sustainable development of the industry and its competitiveness at the international level.

## DISCUSSION

The discussion on financial, economic and logistical management in the agri-food sector of Ukraine in the context of greening smart production is based on the analysis of various scientific approaches and models proposed in the literature.

Panasenko (2024) examines the impact of digitalization on the development of the agri-food sector, emphasizing its key role in increasing the efficiency of logistics processes and financial management. At the same time, Kasych et al. (2020) emphasize the importance of corporate environmental responsibility, which should be integrated into the strategy of agri-food enterprises. However, digitalization and greening require significant investments, which, according to Zoria et al. (2022), is possible only if effective investment support mechanisms are developed.

Bakhmat et al. (2022) focus on training specialists for sustainable economic development, which is consistent with the research of Gryshchenko et al. (2021), who consider innovative educational clusters as a factor of competitiveness. At the same time, Kubitskyi et al. (2024) draw attention to the assessment of the impact of innovative technologies on global competitiveness, which indicates the need for a comprehensive approach to change management.

Regarding the financial component, Mazur et al. (2021) investigate the improvement of controlling in financial management, which allows for an increase in the efficiency of resource use. However, Navrotskyi and Palyukh (2015) emphasize the importance of state financing of the development of the agricultural sector, because without appropriate support, even effective financial instruments may be insufficient.

A separate aspect is logistics and its role in the stability of food supply. Stolyarov et al. (2022) analyze the optimization of material and technical supply, which is important for ensuring the effective allocation of resources. In this context, Hryhoruk and Makarov (2018) emphasize the importance of an integrated assessment of the level of agricultural potential of regions for better forecasting and distribution of financial flows.

Regarding the environmental aspect, Khodakivska et al. (2022) investigate the economic security of innovative entrepreneurship, emphasizing the importance of sustainable development. This echoes the study by Kyryliuk et al. (2021), who analyze the economic factors of ensuring the safety and quality of livestock products, which is key to sustainable financial and economic management.

Finally, Li et al. (2012) proposes a system dynamic model for the analysis of eco-agricultural systems, which can be used to develop integrated management strategies. At the same time, Gabbert et al. (2010) emphasize the analysis of uncertainty in integrated assessments, which is critical for predicting the effectiveness of environmental policies in the agricultural sector.

Thus, the literature demonstrates various approaches to modelling financial, economic and logistical management in the agri-food sector, but the question of integrating environmental factors into financial and economic models and optimizing state regulation mechanisms to support innovation processes remains open.

## CONCLUSIONS

The conclusions of the study confirm the importance of a comprehensive approach to assessing financial, economic and logistical management in the agri-food sector of Ukraine in the context of the greening of smart production. The proposed integrated assessment methodology allows taking into account a wide range of socio-economic, environmental and logistical factors affecting the development of the industry.

Analysis of the dynamics of integrated assessments for 2014–2021 showed the presence of significant fluctuations in financial, economic and logistical indicators, which are due to the macroeconomic situation, technological changes and environmental challenges. The largest drop was observed in 2015, which was due to a decrease in the volume of production, retail sales and exports of food products. The recovery of the industry began in 2016, and after 2018 there was a significant increase in the main indicators, which indicates adaptation to market conditions and the intensification of logistics processes.

The results of the study also emphasize the importance of implementing digital technologies in financial, economic and logistical management, which will help increase the efficiency of decision-making and reduce uncertainty in forecasting the development of the industry. In addition, the integration of environmental standards into production and logistics is a necessary condition for ensuring the sustainable development of the agri-food sector.

The results obtained indicate that effective financial, economic and logistical management of the agri-food sector of Ukraine is a key factor in ensuring its sustainable development. The introduction of mathematical modelling methods, in particular integral assessment and the principal component method, allows for a more accurate analysis of the state of the industry, taking into account the complex impact of economic, logistical and environmental factors.

An important aspect of the study is that integral assessments allow not only to assess the current state of the agri-food sector but also to predict its development in the future. This is especially relevant in the context of rapid economic changes, market globalization and environmental challenges. The use of normalization of indicators and determination of weight coefficients based on the principal component method helps to increase the accuracy of the assessment and provides the possibility of objective comparison of the dynamics of the development of various subsystems of the agri-food sector.

Thus, the results obtained confirm the need for an integrated approach to the management of financial and logistical processes in the agri-food sector. The use of digital technologies, the implementation of environmentally friendly solutions and the further integration of analytical methods into the process of making management decisions will contribute to increasing the sustainability and competitiveness of the Ukrainian agri-food sector at the international level. For further research, a promising direction is the development of adaptive models for forecasting and optimizing financial and logistical processes, which will take into account modern trends in digitalization, climate change and global economic challenges.

Thus, further research should focus on developing strategies for digitalizing the agri-food sector, optimizing financial flows, and improving logistics chains, taking into account environmental factors, which will increase the competitiveness of Ukrainian agri-food production at the international level and ensure its sustainability in the face of global challenges.


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## ADDITIONAL INFORMATION

### AUTHOR CONTRIBUTIONS

*All authors have contributed equally.*

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*The Authors declare that there is no conflict of interest.*

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## МОДЕЛЮВАННЯ ФІНАНСОВО-ЕКОНОМІЧНОГО ТА ЛОГІСТИЧНОГО УПРАВЛІННЯ В АГРОПРОДОВОЛЬЧІЙ ГАЛУЗІ УКРАЇНИ В УМОВАХ ЕКОЛОГІЗАЦІЇ СМАРТВИРОБНИЦТВА

Автори досліджують особливості фінансово-економічного та логістичного управління в агропродовольчій галузі України з урахуванням сучасних тенденцій екологізації та впровадження смартвиробництва. Обґрунтовано необхідність розробки інтегральних оцінок для аналізу стану галузі та її підсистем, що дозволяє враховувати широкий спектр економічних, соціальних та екологічних факторів. Запропоновано комплексний підхід до моделювання управлінських процесів, який базується на застосуванні математико-статистичних методів, зокрема багатовимірного аналізу, методу головних компонент і нормалізації показників.

У процесі дослідження розроблено методику оцінювання ключових аспектів агропродовольчої галузі, яка включає визначення множини статистичних показників, їх структуризацію та поділ на стимулятори й дестимулятори, що дає змогу отримати об'єктивну картину змін у галузі. Виявлено, що цифровізація управлінських процесів відіграє ключову роль у забезпеченні ефективності фінансово-економічного регулювання, підвищенні точності аналітичних даних і прогнозуванні подальшого розвитку галузі. Упровадження смарттехнологій не лише дозволяє оптимізувати логістичні потоки, а й сприяє підвищенню екологічної стійкості аграрного виробництва за рахунок раціонального використання ресурсів і зменшення впливу на довкілля.

Результати дослідження підкреслюють необхідність подальшого вдосконалення механізмів управління агропродовольчою галуззю з урахуванням екологічних викликів і глобальних тенденцій цифрової трансформації. Запропонована методика може бути використана як інструмент для оцінювання ефективності управлінських рішень, що сприятиме формуванню збалансованої стратегії розвитку агропродовольчого сектора в Україні.

**Ключові слова:** моделювання, агропродовольча галузь, сільське господарство, харчова промисловість, сталий розвиток, смартвиробництво, екологізація, логістичне управління, фінансово-економічне управління

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