ISSN: 2221-1055
E-ISSN: 2413-2322

Національний науковий центр «Інститут аграрної економіки»

ЕКОНОМІКА АПК

Науково-виробничий журнал

Заснований у 1994 році
Випускається 6 разів на рік

Том 32, № 2

Київ – 2025

Рік заснування: 1994

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Національного наукового центру «Інститут аграрної економіки»
(протокол № 4 від 13 березня 2025 р.)

Рішення Національної ради України
з питань телебачення і радіомовлення № 1498,
протокол № 15 від 09.05.2024.
Ідентифікатор медіа – R30-04656.

Журнал входить до Переліку наукових фахових видань України
Категорія «А». Спеціальності: С1 (051) – Економіка, D1 (071) – Облік і оподаткування, D2 (072) – Фінанси, банківська справа, страхування та фондовий ринок, D3 (073) – Менеджмент, D7 (076) – Підприємництво та торгівля
(наказ МОН України від 24 лютого 2025 року № 349)

Журнал представлено у міжнародних наукометричних базах даних, репозитаріях та пошукових системах: Google Scholar, Фахові видання України, Національна бібліотека України імені В. І. Вернадського, Crossref, AGRIS, German Union Catalogue of Serials, Econlit, ECONBIZ, UCSB Library, ZBW, WorldCat, JournalFinder, EZB, Litmaps, Ulrichsweb Global Serials Directory, InfoDase, PBN, UBL, TIB, I2OR, BASE, ERIH PLUS, EBSCO, Open Ukrainian Citation Index, EuroPub, Dimensions, University of Oslo Library, University of Hull Library, Search Oxford Libraries Online, European University Institute, Cambridge University Library, Scopus

Адреса редакції:
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ISSN: 2221-1055
E-ISSN: 2413-2322

National Scientific Centre “Institute of Agrarian Economics”

EKONOMIKA APK

Scientific and Production Journal

Founded in 1994
Published six times per year

Volume 32, No. 2

Kyiv – 2025

Year of foundation: 1994

Recommended for printing and distribution
via the Internet by the Academic Council
of the National Scientific Centre "Institute of Agrarian Economics"
(Minutes No. 4 of March 13, 2025)

Decision of the National Council
of Television and Radio Broadcasting of Ukraine No. 1498,
Minutes No. 15, dated 09.05.2024.
Media identifier – R30-04656.

Journal is included in the List of Scientific professional publications of Ukraine
Category "A". Specialties: 0311 – Economics, 0411 – Accounting and Taxation, 0412 – Finance, Banking and Insurance, 0413 – Management and Administration, 0416 – Wholesale and Retail Sales
(order of the Ministry of Education and Science of Ukraine No. 349 dated February 24, 2025)

Journal is presented international scientometric databases, repositories and scientific systems: Google Scholar, Professional publications of Ukraine, Vernadsky National Library of Ukraine, Crossref, AGRIS, German Union Catalogue of Serials, Econlit, ECONBIZ, UCSB Library, ZBW, WorldCat, JournalFinder, EZB, Litmaps, Ulrichsweb Global Serials Directory, InfoDase, PBN, UBL, TIB, I2OR, BASE, ERIH PLUS, EBSCO, Open Ukrainian Citation Index, EuroPub, Dimensions, University of Oslo Library, University of Hull Library, Search Oxford Libraries Online, European University Institute, Cambridge University Library, Scopus

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Редакційна колегія

EKONOMIKA APK Volume 32, No. 2

Editorial Board

ЗМІСТ /CONTENTS

Received: 16.08.2024. Revised: 15.12.2024. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.10

Ekonomika APK, 32(2), 10-27

UDC 338.432

Development of integration structures in the agricultural sector of the economy in wartime conditions

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▸ **Abstract.** The activation of integration structures is of particular importance in the system of enhancing the solvency, competitiveness, and adaptability of the agricultural sector of the economy, as well as stabilising food security in the context of integration with the European community. The aim of the article was to substantiate the theoretical and methodological, socio-economic foundations, and the issues of developing integration structures in rural areas under extreme conditions of operation. The methodological basis of the research was grounded in the principles of modern institutional economic theory, functional and systemic analysis. Monographic, economic-statistical, graphical, structural-functional, and abstract-logical methods and approaches were employed to summarise the results. The current state, place and role of integration structures have been examined. A systematic analysis of the problems and trends in the functioning of integration structures during wartime has been conducted. The theoretical and methodological aspects of the functioning of integration formations have been considered. The reasons that hinder the activation of the integration movement in the agricultural sector of the economy at the present stage of development have been identified. The dynamics of the development of existing large entrepreneurial structures in Ukraine have been assessed, and negative aspects that need to be considered when organising and functioning of integration associations depending on the type and activity of the association have been identified. The role of international technical assistance and state support in stimulating and strategising the development of integration structures in Ukraine has been clarified. Opportunities and prospects for the development of the integration movement and the issues of sustainable development of integration structures have been identified. It has been established that one of the priority areas of regional policy is the development of integrated formations of the agribusiness holding type and cooperative structures in rural areas. The role of integration structures in the formation of social capital and sustainable development of rural territories in the post-war reconstruction of Ukraine's economy has been

▸ **Suggested Citation**: Kravchenko, S., Malik, M., & Shpykuliak, O. (2025). Development of integration structures in the agricultural sector of the economy in wartime conditions. *Ekonomika APK*, 32(2), 10-27. doi: 10.32317/ekon.apk/2.2025.10.

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revealed. The informational material can be used in the development of programmes for the advancement of large entrepreneurial structures in the agrarian business of the regions

▸ **Keywords:** business entity; business structures; integrated formations; agrarian business; agroholding; cooperative

▸ Introduction

Identification of the peculiarities of the processes of development of integration entrepreneurial structures in the context of armed conflict is focused on solving socio-economic problems of peasants; ensuring financial and credit components of competitiveness of business entities; increasing productivity and efficiency of resource management; increasing gross added value; ensuring environmental safety of the high-quality raw material base; implementing modern methods of soil cultivation, rational water use, automation and mechanisation of production processes, modern methods of storage, processing and marketing of products, resource and energy-saving production technologies and digital technologies; using drones and modern monitoring systems; enhancing innovation of business activities, etc.

Noteworthy are the results of the assessment of the socio-economic mechanism of the functioning of entrepreneurship in agriculture in extreme crisis conditions, which are reflected by M. Nehrey & O. Trofimtseva (2022). It is particularly important to preserve the development of human capital in rural areas, given the decline in the purchasing power of citizens, labour migration, occupation of territories, shrinking domestic market niches of enterprises, breakdown of logistics chains, etc. Focusing on the need for the survival and development of cooperative-integration relations, V. Kyfyak *et al.* (2022) emphasise the importance of solving such a significant problem as the lack of sources of financing for their own business in a market environment. And the results of research by S. Pasko (2022) show that holdings or large integrated structures that support the environmental safety of a high-quality raw material base in the context of a system of "sustainable" governance and corporate social responsibility are generators of innovations in the development of entrepreneurship in agriculture. The results of the research by O. Chorna *et al.* (2022) substantiate the reasons for the difficulty of diagnosing the state of economic security of holdings, in particular, the hierarchy of agricultural holdings as business entities; fragmentation, unsystematic and lack of coordination of the processes of diagnosing the state of economic security of economic security components.

A group of scientists O. Shpykuliak *et al.* (2023b) revealed the state and trends in the development of entrepreneurship in agriculture in extreme operating conditions, the degree of restructuring and innovation of business entities, business preservation strategies, and a system for optimising the cost of resource provision for agricultural production. Factors hindering the development of business entities in agriculture include: a decline in the quality of demand for food in the domestic market and human capital in rural communities; imperfect investment and innovation support for innovations; lack of projects to support the development of non-agricultural and communal entrepreneurship in rural areas, etc. Researchers A. Shevchenko & O. Petrenko (2023) revealed the main factors of inhibition and priority factors of socio-economic development of entrepreneurship in rural areas, reducing the level of unemployment of peasants and stimulating self-employment. The mechanisms for the development of investment and innovation technologies of business entities in agriculture and encouragement of start-up financing are substantiated. Small and medium-sized businesses need to form agricultural cooperatives; stimulate investment in organic agricultural production; and introduce scientifically based crop rotation systems, precision farming technologies, energy and resource-saving production technologies.

The results of research by T. Vlasenko (2023) substantiate the need to combine the processes of production, processing and sale of products of business entities into a technological chain, reveal the data on the scale effect, and focus on the formation of integrated structures in the agricultural sector of the economy and their advantages. Additional positive aspects of the functioning of integrated structures include optimisation of financial flows and the taxation system; diversification of production; elimination of regional intermediaries; minimisation of costs; and introduction of new technologies. The synergistic effect is the main advantage of agriholdings. The group of scientists O. Naumov & O. Naumova (2023) emphasises that clustering is the most effective form of integration of agricultural and agro-industrial production entities. The author substantiates the programme for the development of clusters as integrated agro-industrial formations and the implementation of strategic planning. The institutional regulation of agro-industrial production development is facilitated by overcoming the disparity in prices for products, solving socio-economic problems in rural areas, forming an adequate incentive policy, intensifying investment and innovation activity, specialisation of business entities for the raw material base of specific processing enterprises, etc. Researchers Y. Danko & N. Zhurbenko (2023) substantiate that the mechanism of agrarian clustering contributes to cost optimisation, efficient use of available resources, diversification of production, implementation of joint efforts and innovations of business entities. Clustering is a tool for creating competitive innovative agriculture in the context of high risk and European integration challenges.

The authors of P. Kutsyk *et al.* (2023) reveal the state of development of agricultural cooperation in modern conditions and European integration challenges and substantiate that: a) a high level of unity; care for its members; organisational, human, social capital are the advantages of cooperation; b) it is extremely necessary to form purchasing and selling, production, service, agricultural cooperatives; cooperatives for the provision of services. A group of scientists A. Panteleimonenko &

V. Honcharenko (2023) substantiated some of the difficulties of being unready to create a cooperative (lack of special training of existing peasant entrepreneurs; unwillingness to take personal responsibility; socio-psychological inertia of entrepreneurs; low trust in employees of the production process; lack of understanding of the benefits of mutual assistance; unwillingness to pay for services; rejection of "collectivist values"; lack of faith in systemic support from the state, etc).

N. Kryvenko (2024) suggests that the main goals of agrarian integration include solving social problems in rural areas; providing the population with high-quality, environmentally friendly and competitive products at an affordable price; rational use of resources; increasing exports; activating investment and innovation potential, etc. From the standpoint of functional analysis, I. Kosach (2024) substantiates theoretical and applied principles of strategic management of capitalisation of business entities. Attention is focused on the cost of business operation; geopolitical risks; market capitalisation of entrepreneurial activity; strategies of planning, motivation, communication, stimulation of investment attractiveness; the state of development of the financial and credit market; adaptability and success of the management decision-making system in financial management. The authors M. Ihnatenko *et al.* (2024) reveal the main factors of development of large innovative agricultural holdings and prove that the introduction of advanced technologies in the production process increases the efficiency of business entities, the level of product quality, storage and export capacities. Agriholdings based on public-private partnerships can be additional sources of investment for the development of small and medium-sized enterprises. And economist O. Demchenko (2024) focuses on the complexity of legal regulation of cooperatives; the peculiarities of integrating small and medium-sized producers; and improving information support.

However, a number of issues related to the mechanism of functioning of integration business structures in agriculture in extreme crisis conditions remain insufficiently researched and require further consideration. The purpose of the article was to evaluate and substantiate, from the point of view of the system-functional approach, the practical, theoretical and methodological foundations of the economics of the activity of integration business structures in the agro-industrial complex in wartime.

▸ Materials and methods

The research was based on the Law of Ukraine No. 1087-IV (2003); Law of Ukraine No. 3587-IX (2024); Law of Ukraine No. 3528-IV (2024). The information base also included the Economic Code of Ukraine No. 436-IV (2003); Land Code of Ukraine No. 2768-III (2001). In addition, the study used data from publications of national and international news agencies, in particular, Kernel Holding S.A. Annual report (2023); State Statistics Service of Ukraine (2024); Dynamics of the land bank (2024). The results of the works of Ukrainian and foreign scientists on the development of entrepreneurship and integration structures in agriculture in crisis conditions were taken into account (Kaletnik *et al.*, 2022; Kutsyk *et al.*, 2023; Stender *et al.*, 2024).

System-functional analysis and positions of institutional economic theory are the theoretical and methodological basis of the study. Abstract and logical methods were used to determine the essence of the processes of survival of integration structures in rural areas and in agricultural business in the context of the crisis and, in particular, in the synthetic analysis of the peculiarities of the socio-economic mechanism of functioning of agricultural holdings and cooperative formations in extreme conditions. The article also uses structural-functional, statistical, graphical methods and approaches to generalising the results to establish cause-and-effect relationships in characterising the development of certain groups of large business structures and formulating conclusions.

The solution of a system of normal equations and the least-squares method were used to establish the parameters a_0, a_1:

$$y = a_0 + a_1 \cdot x; \tag{1}$$

$$\begin{cases} a \cdot \sum x^2 + b \cdot \sum x = \sum x \cdot y \\ a \cdot \sum x + b \cdot n = \sum y \end{cases}, \tag{2}$$

where y – the theoretical values of the effective characteristic; a_0 – the start of the countdown under the condition that $x=0$; a_1 – the regression coefficient; x – the value of the factor feature; n – the number of observations.

As a result of solving the system, the values of the coefficients a_0, a_1 and analytical expression of the dependency were obtained:

$$y = a_0 + a_1 \cdot x. \tag{3}$$

Kramer's formulas was also calculated, which look like this:

$$x1 = \frac{\Delta 1}{\Delta};\ x2 = \frac{\Delta 2}{\Delta}, \tag{4}$$

where $x1$ and $x2$ – the unknown elements of the system; Δ – the determinant of the system matrix; $\Delta 1$ and $\Delta 2$ – the determinants of matrices $A1$ and $A2$, respectively; $A1$ and $A2$ – the matrices obtained from the system matrix by replacing the corresponding column with the vector of right-hand sides of the system.

The coefficients of determination and correlation were calculated using the following substitute formulas:

$$r = \frac{\sum\left(t_{x_i} \cdot t_{y_i}\right)}{n} = \overline{t_{x_i} \cdot t_{y_i}}; \tag{5}$$

$$t_x = \frac{x_i - \overline{x}}{\sigma_x};\ t_y = \frac{y_i - \overline{y}}{\sigma_y}; \tag{6}$$

$$\sigma_x = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n}};\ \sigma_y = \sqrt{\frac{\sum (y_i - \overline{y})^2}{n}}; \tag{7}$$

$$d = r^2, \tag{8}$$

where $\bar{y}$ – the mean value of the resultant characteristic; $\bar{x}$ – the average value of the factor trait; i – the experiment; r – the linear correlation coefficient; t_x, t_y – the intermediate indicators for calculation; σ_x – the standard deviation of the factor trait; σ_y – the standard deviation of the resultant trait; d – the coefficient of determination, the

calculation of which makes it possible to determine one of the shares of total variation, factor and resultant signs.

The use of the above equations and coefficients helps to establish how changes in agricultural policy and structures of cooperation between business entities affect economic performance. The period of 2012-2023 was taken for the study. Some indicators of economic activity of operating large business structures in agriculture for 2023 were not made public in order to comply with the requirements of the Law of Ukraine No. 2524-IX (2022) to ensure the guarantees of state statistics authorities regarding statistical confidentiality. To make the necessary calculations and establish a forecast for 2030 of annual changes in agricultural products sold by large business structures and net profit, as well as the impact of the total cost of sales Kernel Holding S.A. (Kernel Holding S.A. Annual…, 2023) net sales revenue was based on web versions Word, Excel and peculiarities of the trend analysis.

Results and discussion

The country's socio-economic, organisational and management system is gradually adapting to functioning in extreme conditions, reputational and European integration challenges. In 2023, compared to 2022, the gross domestic product grew by 5.3%. Increased logistics and labour costs, a shortage of qualified personnel, and damage to energy facilities hinder the systematic planned strategic development of business entities and integration structures in the agricultural sector of Ukraine. It was found that the number of operating large business structures in agriculture over the past 12 years has increased almost 3 times in 2021, but in 2022, due to military aggression, it decreased by 20.41% (Fig. 1). The number of employed workers in large business structures was highest in 2015 (48.275 people) and lowest in 2017 (27.537 people). Due to the outbreak of hostilities, the total number of employed workers decreased by 20.43% (Fig. 2).

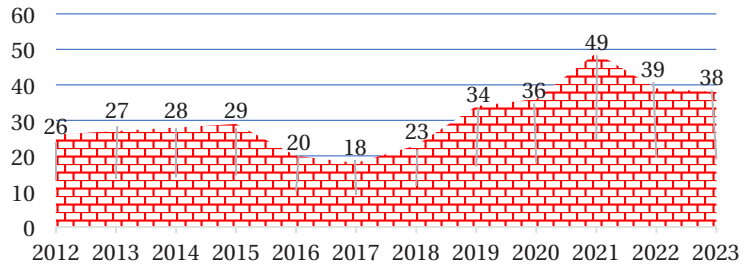

Figure 1. Operating large business structures, units
Source: State Statistics Service of Ukraine (n.d.)

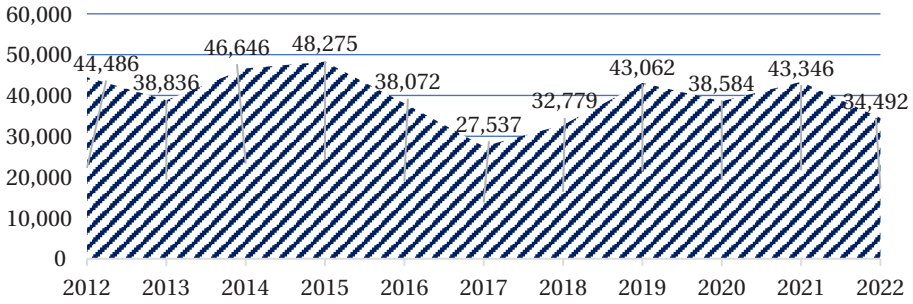

Figure 2. Number of employees in large business structures, persons
Notes: there is no data published for 2023
Source: State Statistics Service of Ukraine (n.d.)

In the period 2018-2022, the dynamics of changes in the key economic performance indicators of existing large business structures in agriculture is characterised by a sharp decline in net profit, profitability of operating and total activities, balance sheet, and an increase in production costs (goods and services), short-term bank loans in 2019 and 2022. It was found that during the wartime period of 2022-2024 alone, the loan portfolio of the real sector of Ukraine's economy decreased by 2.6 billion UAH. In particular, as of the beginning of April 2024, it stood at 787.549 billion UAH. However, loans to large businesses accounted for only 23.44% of this loan portfolio, and collateralised loans to agricultural businesses accounted for 14%. The quality of the loan portfolio is highest among rural entrepreneurs. In fact, the outbreak of the armed conflict in Ukraine has had a negative impact on the socio-economic, organisational, managerial, financial and credit status of large agricultural businesses and the sustainable development of local communities. Thus, in 2022, the following indicators of economic activity of operating large business structures in agriculture decreased: net profit by –62.38%; profitability of all activities by –27.9%; capital in revaluation and additional capital by –18.43%; volume of products (goods, services) by –15.53%; social contributions by –15.36%; volume of products sold by –2.87%; retained earnings (uncovered loss) by –1.68%. Some statistics for 2023 have not yet been made public. In 2023, compared to 2018, net profit increased by +6.06%; current assets by +2.76 times; current liabilities and collateral by +2.03 times; equity by +2.28 times; depreciation by

+2.9 times. The level of profitability of all activities in 2023 decreased by –12.6% compared to 2018. However, in 2023, compared to 2021: a) net profit decreased by –4.04 times; profitability by –4.93 times; equity by –1.5%; b) current assets increased by +8.88%; current liabilities and collateral by +0.15% (Table 1).

Table 1. Main indicators of economic activity of existing large business structures in agriculture (million UAH; in constant prices of 2016; end of year)

Indicators	2018	2019	2020	2021	2022	2023	2022 in % up to 2018
The volume of products (goods, services) produced	63,282.8	80,991.8	90,514.9	130,042.0	109,850.9	nd	**+73.59**
The volume of products sold	54,757.9	74,131.9	78,052.2	114,806.3	111,514.9	nd	**+103.6**
Value added by production costs	5,912.9	9,900.0	36,568.2	54,313.4	28,292.8	nd	**+378.5**
Net profit	11,217.5	5,026.2	8,677.6	48,273.2	18,158.9	11,941.8	**+61.88**
Profitability level of all activities, %	21.2	6.1	9.7	42.4	14.5	8.6	**–31.60**
Current assets	56,519.7	76,357.2	87,440.8	143,322.6	158252.2	156,062.4	**+179.9**
Current liabilities and provisions	37,975.1	58,428.4	68,122.9	77,003.7	84,892.4	77,116.9	**+123.5**
Equity capital	63,650.0	91,592.9	99,557.1	147,381.6	145,514.8	145,162.8	**+128.6**
Costs of production (goods, services), including:	66,029.9	84,883.5	70,174.4	99,772.7	100,742.4	nd	**+52.57**
Amortisation	3,709.9	6,531.2	7,659.0	9,984.1	9,292.8	10,772.2	**+150.5**
Labour costs	3,993.9	6,787.1	6,797.9	8,782.6	7,575.4	nd	**+89.67**
Contributions to social activities	807.0	1,298.5	1,401.6	1,773.4	1,500.9	nd	**+85.98**
Personnel costs	4,800.9	8,085.6	8,199.5	10,556.0	9,076.3	nd	**+89.05**

Notes: nd – no data published
Source: State Statistics Service of Ukraine (n.d.)

The study revealed a functional relationship between the volume of products sold by operating large business entities and their net profit for 2018-2022 in million UAH at constant prices of 2016 (Tables 2-3).

Table 2. Information data for establishing the relationship between profit indicators and the volume of products sold by operating large business structures

Indicators	2018	2019	2020	2021	2022	2023
Products sold, **Xi**	54,757.9	74,131.9	78,052.2	114,806.3	111,514.9	nd
Net profit (loss), **Yi**	11,217.5	5,026.2	8,677.6	48,273.2	18,158.9	11,941.8

Notes: nd – no data published
Source: State Statistics Service of Ukraine (n.d.)

Table 3. Estimated values of intermediate indicators for establishing a linear dependence function

	x_i^2	x	y	y_i^2	$x_i y_i$
1	**2,998,427,612.41**	54,757.9	11,217.5	**125,832,306.25**	**614,246,743.25**
2	**5,495,538,597.61**	74,131.9	5,026.2	**25,262,686.44**	**372,601,755.78**
3	**6,092,145,924.84**	78,052.2	8,677.6	**75,300,741.76**	**677,305,770.72**
4	**13,180,486,519.69**	114,806.3	48,273.2	**2,330,301,838.24**	**5,542,067,481.16**
5	**12,435,572,922.01**	111,514.9	18,158.9	**329,745,649.21**	**2,025,042,394.31**
Σ	**40,202,171,576.56**	**433,263.2**	**91,353.4**	**2,886,443,221.90**	**9,231,264,145.22**

Source: authors' development based on formulas (1-4)

Using formulas (1-4), it was calculated and obtained the following results: $a = 0.494683$; $b = -24{,}594.97$; $y = 0.494683 \cdot x - 24{,}594.97$. It was found that with an increase in the volume of agricultural products sold by large business structures by 1 million UAH, net profit increases by 0.494683 million UAH. Next, the correlation coefficient was calculated (Table 4).

Table 4. Estimated values for determining correlation and determination coefficients

	x	$x_i - \bar{x}$	$(x_i - \bar{x})^2$	y	$y_i - \bar{y}$	$(y_i - \bar{y})^2$	t_x	t_y	$t_x t_y$
1	54,757.9	**–31,894.74**	**1,017,274,439.667**	11,217.5	**–7,053.18**	**49,747,348.112**	**–1.52**	**–0.45**	**0.6840**
2	74,131.9	**–12,520.74**	**15,676,893,014.760**	5,026.2	**–13,244.48**	**175,416,250.470**	**–0.20**	**–0.85**	**0.1700**
3	78,052.2	**–8,600.44**	**73,967,568.193**	8,677.6	**–9,593.08**	**92,027,183.886**	**–0.14**	**–0.61**	**0.0854**
4	114,806.3	**28,153.66**	**792,628,571.395**	48,273.2	**30,002.52**	**900,151,206.350**	**1.46**	**1.92**	**2.8032**
5	111,514.9	**24,862.26**	**618,131,972.307**	18,158.9	**–111.78**	**12,494.768**	**0.41**	**–0.01**	**–0.0041**
Σ			**18,178,895,566.324**			**1,217,354,483.588**			

Source: authors' development based on formulas (5-8)

Calculated using formulas (5-8), there is the following data: $R = 0.9127$; $D = 0.8330$. That is, in the period 2018-2022, 83.30% of the variation in net profit is explained by the variation in the level of agricultural products sold by large business structures. The impact of other factors is not significant (Fig. 3).

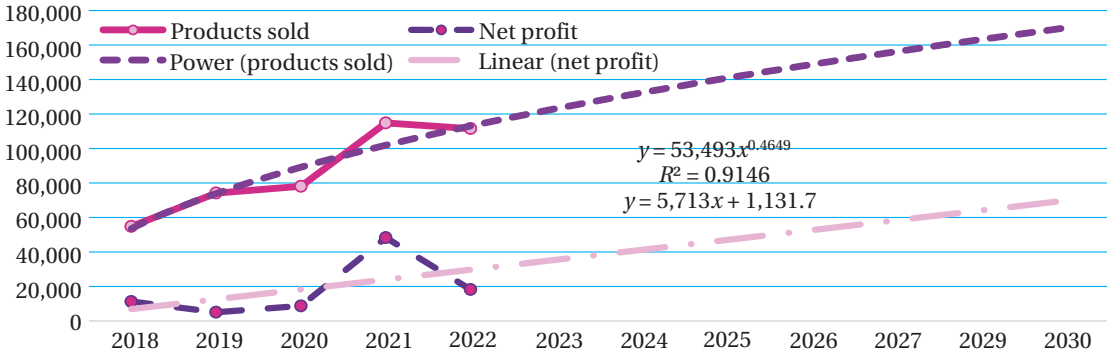

Figure 3. Forecast of changes in products sold by large business structures and net profit in 2030 (million UAH; in constant 2016 prices)

Notes: $y = 53{,}493 \cdot x^{0.4649}$ – a power function for predicting changes in products sold by large business structures in 2030; $y = 5{,}713x + 1{,}131.7$ – a linear function of forecasting changes in the net profit of large business structures in 2030; the correlation coefficient is 0.9146

Source: State Statistics Service of Ukraine (n.d.)

The activation of the institution of self-regulation contributes to cost optimisation, building social capital and improving the overall performance of business entities in the agricultural sector of the economy. In addition to mergers (vertical integration) or delegation of functions (horizontal integration) of business entities, the activities of functionally self-regulating associations of agricultural business entrepreneurs for some purpose of obtaining services (associative structures in advisory services, land management, wholesale sales of products, and agricultural land valuation) are stimulated. Among the integration associations of the association type (professional, sectoral, umbrella), the results of the activities of such sectoral associations as the Ukrainian Grain Association (n.d.); Association "Pig Farmers of Ukraine" (n.d.); Association "Union of Poultry Farmers of Ukraine" (n.d.); Milk Producers Association (n.d.); Union of Dairy Enterprise of Ukraine (n.d.). The outbreak of the armed conflict in Ukraine also had a negative impact on the activities of sectoral integration associations. For example, compared to the pre-war year 2020, the following performance indicators of some existing sectoral integration associations decreased in 2023: "Ukrainian Grain Association" – current liabilities (–20.04%), non-current assets, fixed assets (–33.59%); Association "Union of Poultry Breeders of Ukraine" – long-term liabilities, targeted financing and collateral (–98.09%), non-current assets, fixed assets (–95.93); Association of Milk Producers – current liabilities (–99.49%), current assets, inventories (–06.03%), non-current assets, fixed assets (–89.53) (Table 5).

Table 5. Key performance indicators of existing sectoral integration associations of the association type, thousand UAH

Indicators	2020	2021	2022	2023	2023 in % up to 2020
Association "Ukrainian Grain Association"					
Assets	2,650,000	4,234,700	5,725,000	5,086,300	**+91.93**
Non-current assets. Fixed assets	153,300	59,300	211,600	101,800	**–33.59**
Current assets. Inventories	2,496,700	4,175,400	5,513,400	4,984,500	**+99.64**
Liabilities	2,650,000	4,234,700	5,725,000	508,630	**–80.81**
Long-term liabilities, earmarked funding and collateral	2,484,800	3,982,000	5,503,600	4,954,200	**+99.38**
Other current liabilities	165,200	252,700	221,400	132,100	**–20.04**
Income	4,779,700	6,387,700	6,109,800	6,387,800	**+33.64**
Association "Pig Farmers of Ukraine"					
Assets	1,035,600	1,223,300	2,350,900	2,149,600	**+107.6**
Non-current assets. Fixed assets	100	100	100	58,600	**+586 times**
Current assets. Inventories	1,035,500	1,223,200	2,350,800	2,091,000	**+101.9**
Liabilities	1,035,600	1,223,300	2,350,900	2,149,600	**+107.6**
Long-term liabilities, earmarked funding and collateral	1,035,600	1,161,700	1,391,800	1,962,800	**+89.53**
Other current liabilities	0	0	7,700	5,000	**+**

Table 5, Continued

Indicators	2020	2021	2022	2023	2023 in % up to 2020
Income	2,681,700	3,337,700	19,866,900	3,337,700	**+24.46**
Association "Union of Poultry Farmers of Ukraine"					
Assets	3,882,000	4,509,100	4,395,400	4,676,700	**+20.47**
Non-current assets. Fixed assets	1,251,400	917,200	167,600	50,900	**–95.93**
Current assets. Inventories	2,630,600	3,591,900	4,227,800	4,625,800	**+75.84**
Liabilities	3,882,000	4,509,100	4,395,400	4,676,700	**+20.47**
Long-term liabilities, earmarked funding and collateral	2,648,700	3,593,000	161,800	50,500	**–98.09**
Other current liabilities	2,923,000	2,720,500	1,743,900	2,720,500	**–06.93**
Milk Producers Association					
Assets	9,901,000	7,270,900	9,469,500	8,275,300	**–16.42**
Non-current assets. Fixed assets	1,232,000	518,400	145,200	129,000	**–89.53**
Current assets. Inventories	8,669,000	6,752,500	9,324,300	8,146,300	**–06.03**
Liabilities	9,901,000	7,270,900	9,469,500	8,275,300	**–16.42**
Long-term liabilities, earmarked funding and collateral	924,000	6,620,500	8,014,400	5,028,100	**+444.2**
Other current liabilities	6,626,000	87,900	130,800	99,500	**–99.49**
Income	7,554,000	51,653,200	14,131,300	51,653,200	**+6.8 times**
Association "Union of Dairy Enterprises of Ukraine"					
Assets	1,860,000		355,600	1,252,400	**–32.67**
Non-current assets. Fixed assets	45,000		19,800	0	**–**
Current assets. Inventories	141,000		335,800	1,252,400	**+788.2**
Liabilities	186,000		355,600	1,252,400	**+573.3**
Long-term liabilities, earmarked funding and collateral	158,000		340,500	1,252,200	**+692.5**
Other current liabilities	1,081,000		10,596,600	6,671,800	**+517.2**

Source: Clarity-project.info (n.d.)

As of May 2024, 33 million hectares (77.2%) of agricultural land were registered in the state land cadastre. Large businesses in the agricultural sector of the economy concentrate a significant area of agricultural land in their use (3,247.6 thousand hectares in 2023). Agricultural holdings Kernel Holding Sa, MHP S.A., UkrLandFarming PLC (Avangardco IPL), Astarta Holding N.V. for this purpose, they raised funds from global stock exchanges. And the agricultural holding Agroprosperis LLC actively uses an investment fund NCH Capital (USA) (Table 6) (Dynamics of the land bank, n.d.).

Table 6. The size of land use of existing large agricultural business entities as of 01 January of each year, thousand ha

	Business entity	2017	2019	2020	2021	2022	2023	2023 up to 2017
1	Kernel Holding S.A.	602.5	530.0	530.0	506.0	506.0	363.0	**–239.5**
2	MHP S.A.	370.0	370.0	370.0	370.0	370.0	362.0	**–8**
3	UkrLandFarming PLC (Avangardco IPL)	605.0	500.0	500.0	475.0	460.0	310.0	**–295**
4	Agroprosperis LLC	430.0	396.0	300.0	300.0	300.0	300.0	**–130**
5	Astarta Holding N.V.	250.0	250.0	235.0	220.0	220.0	212.0	**–38**
6	Continental Farmers Group	185.0	195.0	195.0	195.0	195.0	195.0	**+10**
7	Epicenter Agro	116.0	121.4	160.0	160.0	160.0	160.0	**+44**
8	Agricultural system technologies	50.0	110.0	110.0	150.0	150.0	150.0	**+100**
9	Harv East Holding LLC	97.0	127.0	127.0	127.0	127.0	127.0	**+30**
10	Industrial Milk Company S.A.	137.0	123.9	123.9	120.0	120.0	120.0	**–17**
11	Agroton PLC	151.0	110.0	110.0	110.0	110.0	110.0	**–41**
12	Agrein Holding Limited	127.0	110.0	110.0	110.0	110.0	110.0	**–17**
13	Ukrprominvest-Agro LLC	122.0	116.5	120.0	120.0	120.0	108.0	**–14**
14	Privat-Agroholding	100.0	85.0	85.0	85.0	85.0	85.0	**–15**
15	Trading company "Vitagro"	64.5	85.0	85.0	85.0	85.0	85.0	**+20.5**
16	TAS Agro LLC	88.0	83.0	83.0	83.0	83.0	83.0	**–5**
17	Agrofirm "Svitanok"	80.0	80.0	80.0	80.0	80.0	80.0	**0**
18	LNZ Group	60.0	80.0	80.0	80.0	80.0	80.0	**+20**
19	Agro Vista Holding	75.0	82.0	82.0	80.0	80.0	75.0	**0**
20	Nibulon S.A.	82.5	82.5	82.5	82.5	82.5	51.0	**–31.5**
21	Agro Generation	120.0	70.0	58.0	56.0	56.0	30.6	**–89.4**

Table 6, Continued

	Business entity	2017	2019	2020	2021	2022	2023	2023 up to 2017
22	KSG Agro S.A.	33.0	27.0	21.0	24.0	24.0	24.0	**–9**
23	Milkiland N.V.	23.0	12.0	12.0	12.0	12.0	17.0	**–6**
24	Agroliga Group PLC	9.9	9.9	10.0	10.0	10.0	10.0	**+0.1**
Total land use size		**3,978.4**	**3,756.2**	**3,669.4**	**3,640.5**	**3,625.5**	**3,247.6**	

Source: Dynamics of the land bank (n.d.)

In general, as of the end of 2022, 109.5 thousand hectares of agricultural land were in circulation in the country, and as of the end of 2023 – 172.9 thousand hectares. The value of agricultural land is constantly growing. In the first half of 2024, 38% of land transactions were concluded by large businesses in the agricultural sector. In May 2024, the weighted average price of a hectare of agricultural land with the designated purpose "for commercial agricultural production" was 46.2 thousand UAH (end of 2023 – 37.7 thousand UAH).

In general, since the beginning of hostilities, the value of corporate business entities in the agricultural sector of the economy has significantly decreased and reflects the state of development of the crisis management system, the effectiveness of making and implementing adaptive strategic decisions to diversify business models in the market environment. The study found that in 2023, the total capitalisation of corporate business entities was EUR 49,642.09 million, which is 25.2% (or EUR 16,721.19 million) less than in 2022. The main reasons for this are the intensification of the armed conflict and doing business in extreme operating conditions; deterioration of the overall environmental, social and economic situation in the country, trading conditions on stock exchanges and stock markets; currency fluctuations and a decline in the price of shares of agricultural holdings, etc. For example, in 2023, the capitalisation of corporate business entities decreased by: Kernel Holding S.A. – 46.91%; MHP S.A. – 32.81% (Fig. 4); IMC S.A. – 47.44%; Milkiland N.V. – 33.87; Agroton PLC – 24.82; KSG Agro S.A. – 23.69; Agroliga Group PLC – 17.72 (Fig. 5).

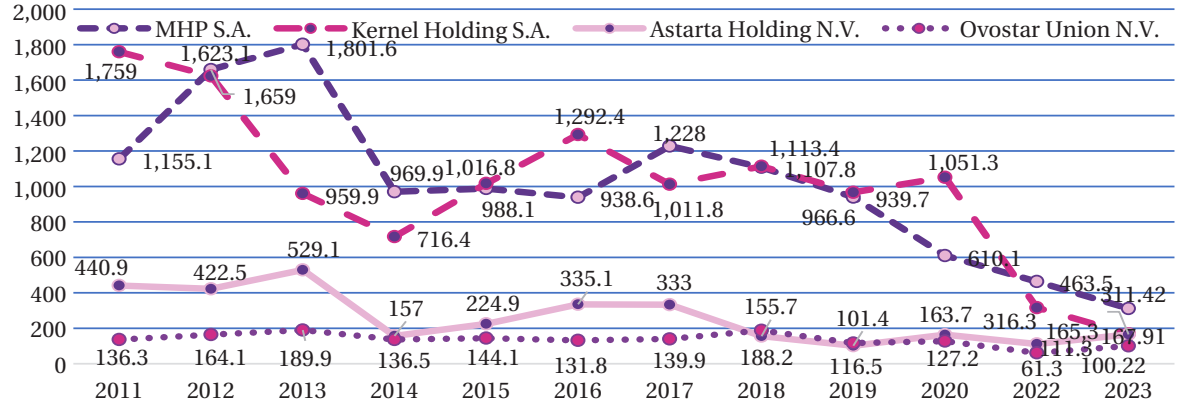

Figure 4. Changes in the capitalisation of public entities
MHP S.A., Kernel Holding S.A., Astarta Holding N.V., Ovostar Union N.V

Notes: as of the end of the year, million USD; 2023 – million EUR
Source: Capitalization (n.d.)

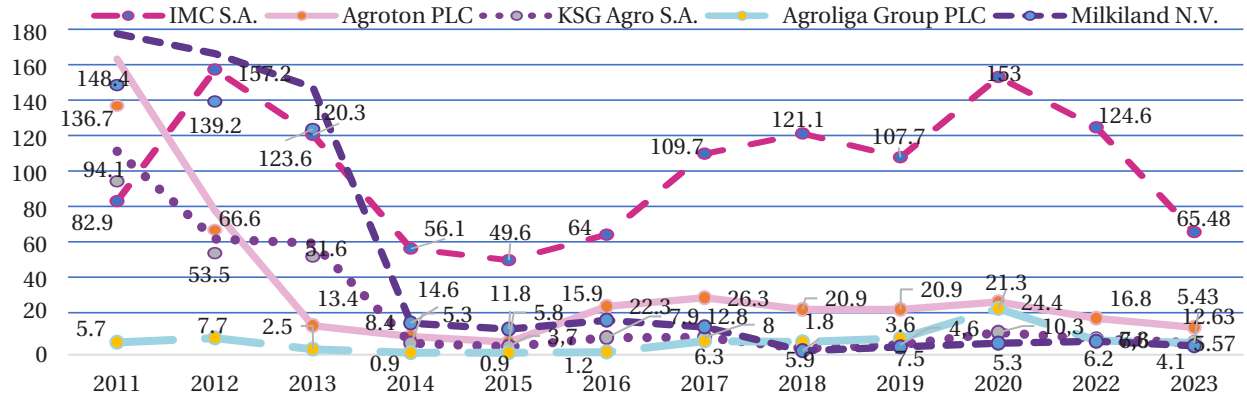

Figure 5. Changes in the capitalisation of public entities
Industrial Milk Company S.A., Agroton PLC, KSG Agro S.A., Agroliga Group PLC, Milkiland N.V.

Notes: as of the end of the year, million USD; 2023 – million EUR
Source: Capitalization (n.d.)

It was also found that the total capitalisation of corporate business entities MHP S.A., Kernel Holding S.A., Astarta Holding N.V., Ovostar Union N.V., Industrial Milk Company S.A., Agroton PLC, Ukrproduct Group Ltd, KSG Agro S.A., Agroliga Group PLC, Milkiland N.V., AgroGeneration for the first quarter of 2024 amounted to EUR 11,554.95 million, which is a decrease of 14.5% compared to the first quarter of 2023. For the second quarter of 2024, the total capitalisation of these large business entities was EUR 11,602.90 million, a decrease of 13.3% compared to the second quarter of 2023. As of 29 July to 5 August 2024, a decrease in capitalisation was observed in Ovostar Union N.V. (–0.6%), AgroGeneration (–3.3%), Industrial Milk Company S.A. (–5.1%), Astarta Holding N.V. (–8.3%), KSG Agro S.A. (–11.1%), Ukrproduct Group Ltd (–12.6%), Milkiland N.V. (–20.3%); capitalisation growth was observed in MHP S.A. (+7.5%), Agroton PLC (+1.0%), Agroliga Group PLC (+3.6%), Kernel Holding S.A. (+4.3%), MHP S.A. (+7.5%) (Table 7).

Table 7. Changes in the capitalisation of public large business structures in the agricultural business in 2024, EUR million

Business entity	01.01	08.01	18.03	25.03	15.04	22.04	29.04	22.07	29.07	05.08	Correlation 05.08 in % up to 01.01
1. MHP S.A.	311.42	326.91	333.53	328.40	323.96	324.57	330.74	379.84	362.79	392.47	**126.03**
2. Kernel Holding S.A.	167.91	326.91	168.29	169.44	208.57	191.24	186.33	217.68	224.58	234.90	**139.89**
3. Astarta Holding N.V.	165.30	165.03	171.05	168.77	162.78	161.38	159.81	162.05	182.64	167.46	**101.30**
4. Ovostar Union N.V.	100.22	96.60	102.28	92.56	97.85	91.12	95.33	97.83	96.07	95.45	**95.240**
5. IMC S.A.	65.48	65.51	72.01	74.43	71.75	64.98	60.46	76.04	98.99	93.91	**143.42**
6. Agroton PLC	12.63	12.31	15.23	15.28	15.35	15.25	15.26	17.51	18.06	18.25	**144.49**
7. KSG Agro S.A.	5.57	5.60	5.44	5.40	5.36	5.17	4.94	8.72	8.99	7.99	**143.45**
8. Agroliga Group PLC	5.43	5.47	5.46	5.54	4.87	5.04	5.03	6.41	6.15	6.38	**117.49**
9. Milkiland N.V.	4.10	3.92	4.20	4.28	4.22	4.35	4.27	9.78	9.85	7.85	**191.46**

Source: Capitalization (n.d.)

One of the conditions for the development of large business structures in the agricultural sector of Ukraine in the face of reputational challenges is a systematic increase in publicity. In 2024, the following companies have the highest: reputational stability – Nibulon (43.25), Industrial Milk Company S.A. (42.40), MHP S.A. (41.33); image capital of corporate social responsibility – Nibulon (41.58), Kernel Holding S.A. (41.33), KSG Agro S.A. (41.00); media activity – Industrial Milk Company S.A. (43.00), Nibulon (41. 83), MHP S.A. (39.11); activity in the implementation of innovative approaches – Industrial Milk Company S.A. (40.40), Nibulon (38.92), Kernel Holding S.A. (37); systematic implementation of anti-crisis strategies of the business model – Nibulon (43.08), Kernel Holding S.A. (42.33), Industrial Milk Company S.A. (41.40), MHP S.A. (41.22) (Fig. 6).

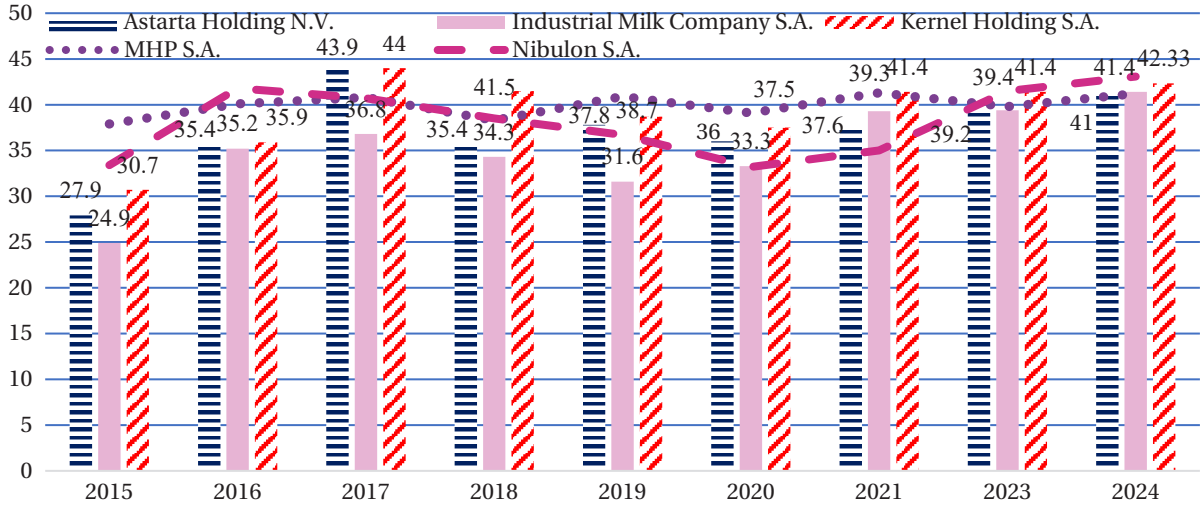

Figure 6. Results of the assessment of corporate reputation management of large enterprises in the agricultural sector of Ukraine in 2015-2024

Source: National rating of the quality of corporate reputation management "Reputation Activists" (n.d.)

It is established that the main task in the corporate reputation management system for large business structures is to solve problems with the lack of specialised specialists and ensure the social and psychological stability of employees. In particular, Kernel Holding S.A., MHP S.A., and Astarta Holding N.V. are implementing an internal programme "Kernel Growth – Leadership Development" and an educational project "Open Agro University". In 2023, the total number of employees of Kernel Holding S.A. was 10,733. This is a significant decrease compared to the pre-war year 2021 (11,256 people) and 2017 (16,103 people) (Fig. 7). In 2015-2023, the largest number of producers worked in farming by business type. In 2023, the number of employees in farming was 4,508, which is 51.99% less than in 2017 and 19.63% less than in pre-war 2021 (Fig. 8). In 2023, the average number of hours of training per employee at Kernel Holding S.A. increased to 30.4 hours, which is 3 times more than in pre-war 2020.

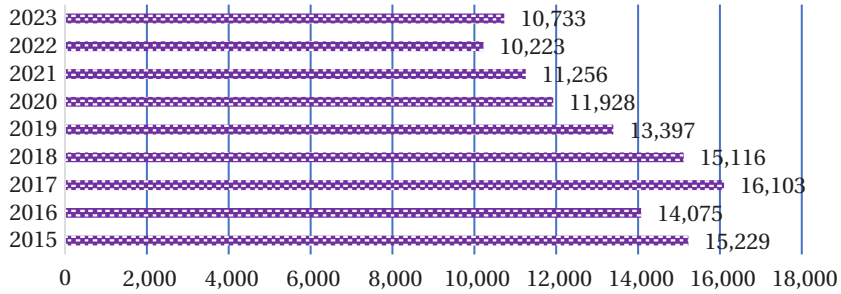

Figure 7. Dynamics of changes in the total number of employees in Kernel Holding S.A., people
Source: Kernel Holding S.A. Annual report (2023)

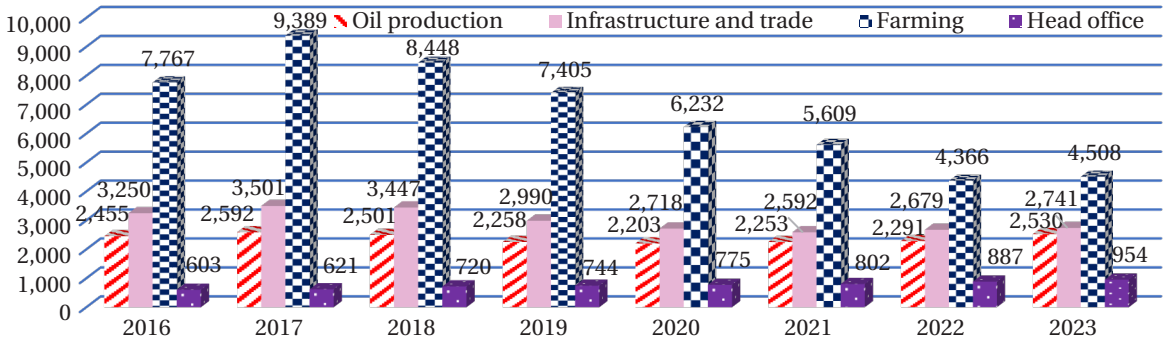

Figure 8. Dynamics of the number of employees by business area in Kernel Holding S.A., people
Source: Kernel Holding S.A. Annual report (2023)

In accordance with the sustainable development goals implemented by Kernel Holding S.A. in 2023, some of the key indicators in 2023 were: a) environmental capital, ESG area – investment rating for climate indicators: changes in the CDP (Carbon Disclosure Project) rating from D to B; b) human capital, ESG area – employment: 10,733 – total number of employees; 2,711 – number of new employees; 2,163 – number of staff turnover; employer rating – the 1st place in the agricultural sector of the economy, 2nd place among all business entities in the country; Forbes Ukraine version – Veterans' adaptation programme, Top 25 companies; the 8th annual HR Brilliance Awards, HR team of the year 2023; c) social capital, ESG area – support for local communities: 12 million USD – support for the army, humanitarian aid (Kernel Holding S.A. Annual..., 2023).

It was found that in 2023, compared to 2021, Kernel Holding S.A.'s revenue from oil production increased by +9.21% or +161 million USD, and from farming activities by +5.78% or +38 million USD. However, in terms of the functioning of the "Infrastructure and Trade" market segment, in 2023, compared to 2021, revenue decreased by –46.43% or by –2.255 million USD. In addition, it was found that in 2023, compared to 2021, sales volumes of products decreased, in particular: oil by –16.67% or by –228 million USD; produced by farms by –35.55% or by –1.020 million USD; in terms of the functioning of the "Infrastructure and Trade" market segment by –53.76% or by –4.308 million USD.

The main indicators of Kernel Holding S.A.'s economic activity for pre-war (MY 2020/2021) and wartime periods (MY 2021/2022, MY 2022/2023) were considered. In MY 2022/2023, net sales revenue decreased to 3,455,121 thousand USD or 38.24% (–2,139,679 thousand USD) compared to MY 2020/2021. The cost of goods sold has been negative: MY 2020/2021 = –4,821,872 thousand USD; MY 2021/2022 = –4,691,973 thousand USD; MY 2022/2023 = –2,704,014 thousand USD. The average annual value of property, plant and equipment decreased insignificantly in 2023 by –0.54% compared to the data of MY 2020/2021. In MY 2022/2023, the average annual output per employee of Kernel Holding S.A. decreased by 175 thousand USD or 35.21%.

The study also revealed the functional dependence of the impact of the cost of goods sold on the net

income from the sale of products of Kernel Holding S.A. for MY 2020/2021, MY 2021/2022, MY 2022/2023 in thousand USD as criteria for assessing the effectiveness of managing the development of the potential of a public corporate business entity in the agricultural sector of the economy of Kernel Holding S.A. (Tables 8-9).

Table 8. Information for determining the impact of cost of goods sold on net income from sales of Kernel Holding S.A., thousand USD

Indicators	MY 2020/2021	MY 2021/2022	MY 2022/2023
Net revenue from sales of products, y_i	5,594,800	5,331,545	3,455,121
Cost of goods sold, x_i	4,821,872	4,691,973	2,704,014

Source: Kernel Holding S.A. Annual report (2023)

Table 9. Estimated values of intermediate indicators for establishing a linear dependence function

	x_i^2	x	y	y_i^2	$x_i y_i$
1	**23,250,449,584,384**	4,821,872	5,594,800	**31,301,787,040,000**	**26,977,409,465,600**
2	**22,014,610,632,729**	4,691,973	5,331,545	**28,425,372,087,025**	**25,015,465,188,285**
3	**7,311,691,712,196**	2,704,014	3,455,121	**11,937,861,124,641**	**9,342,695,555,694**
Σ	**52,576,751,929,309**	**12,217,859**	**14,381,466**	**71,665,020,251,666**	**61,335,570,209,579**

Source: authors' development based on formulas (1-4)

Formulas (1-4) were used and the following results were obtained: a = 0.981288; b = 797,406.7; $y = 0.981288 \cdot x + 797{,}406.7$. It was found that with an increase in net income from sales of Kernel Holding S.A. products by 1 thousand USD, the cost of sales increases by 0.981 thousand USD (Table 10).

Table 10. Estimated values for determining correlation and determination coefficients

	x	x_i-$\bar{x}$	$(x_i$-$\bar{x})^2$	y	y_i-$\bar{y}$	$(y_i$-$\bar{y})^2$	t_x	t_y	$t_x t_y$
1	4,821,872	**749,252**	**561,378,559,504**	5,594,800	**800,978**	**641,565,756,484**	**0.7731**	**0.8408**	**0.6497**
2	4,691,973	**619,353**	**383,598,138,609**	5,331,545	**537,723**	**289,146,024,729**	**0.6390**	**0.5644**	**0.3606**
3	2,704,014	**–1,368,606**	**1,873,082,383,236**	3,455,121	**–1,338,701**	**1,792,120,367,401**	**–1.4121**	**–1.4052**	**1.9843**
Σ			**2,818,059,081,349**			**2,722,832,148,614**			**2.9946**

Source: authors' development based on formulas (5-8)

Calculated using formulas (5-8), there is the following data: R = 0.9982; D = 0.9964. That is, in the period MY 2020/2021, MY 2021/2022, MY 2022/2023, 99.64% of the variation in net income from sales of Kernel Holding S.A. products is explained by the variation in the cost of sales. The most significant factors affecting the net income from sales are social security contributions, direct labour costs, depreciation, cost of seeds and planting material, third-party services, and the cost of mineral fertilisers of Kernel Holding S.A. The forecast of the impact of the total cost of sales of Kernel Holding S.A. on the net income from sales of products in 2030 was calculated (Fig. 9).

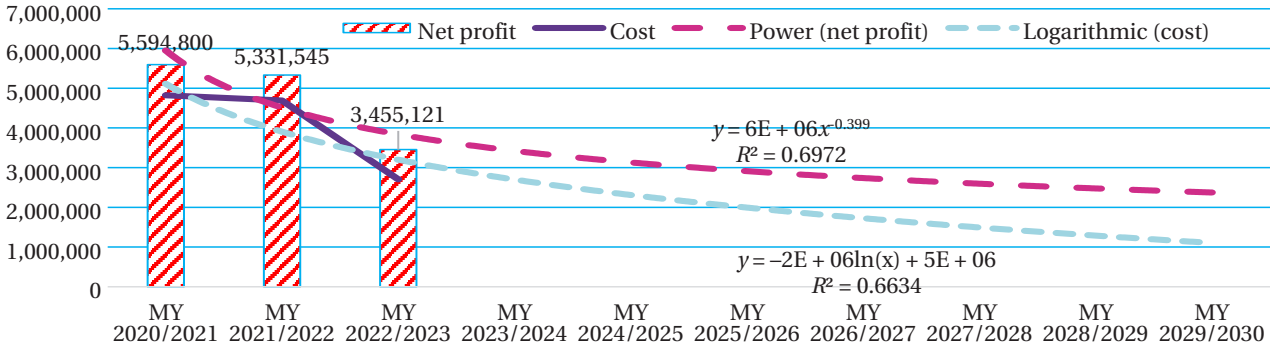

Figure 9. Forecast of the impact of the total cost of sales of Kernel Holding S.A. on net income from sales in 2030, thousand USD

Notes: $y = 6E + 06 \cdot x^{0.399}$ – a power function of the forecast of change in net income of Kernel Holding S.A. in 2030; the correlation coefficient is 0.6972; $y = -2E + 06\ln(x) + 5E + 06$ – the logarithmic function of forecasting the impact of the cost of sales of Kernel Holding S.A. in 2030; the correlation coefficient is 0.6634

Source: Kernel Holding S.A. Annual report (2023)

Due to the beginning of the armed aggression of the Russian Federation and changes in the market environment, the following decreased: gross profit – by 29.72% (or by 269,157 thousand USD); profit from operating activities – by 36.24% (or by 249,833 thousand USD); profit before tax – by 31.62% (or by 170,150 thousand USD); net profit – by 40.92% (or by 206,948 thousand USD) (Fig. 10). The profitability of Kernel Holding S.A. in MY 2022/2023 increased to 124%, which is 10% more than in MY 2021/2022; and 5% more than in MY 2020/2021 (Fig. 11). It was found that in MY 2022/2023, compared to MY 2020/2021, the following decreased: autonomy ratio by –7.22%; current liquidity by –163.05%; absolute liquidity by –23.06% (Fig. 12).

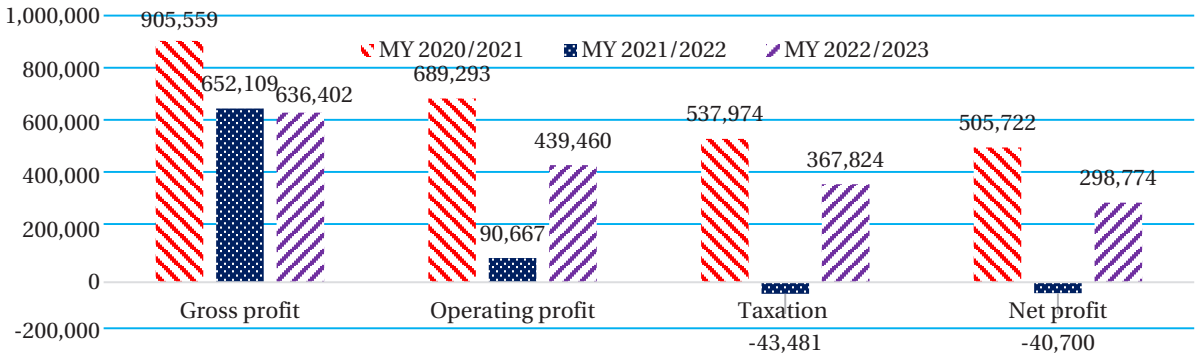

Figure 10. Dynamics of changes in gross profit, profit from operating activities, profit before tax, net profit in Kernel Holding S.A., thousand USD
Source: Kernel Holding S.A. Annual report (2023)

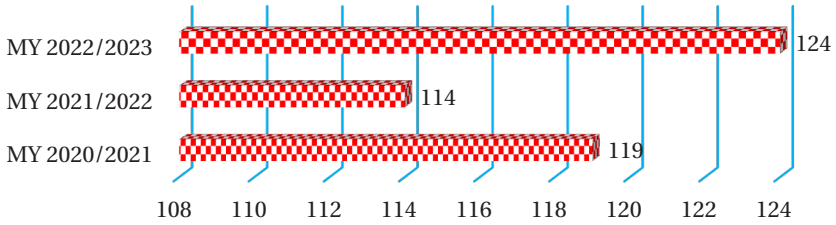

Figure 11. Dynamics of changes in product profitability at Kernel Holding S.A., %
Source: Kernel Holding S.A. Annual report (2023)

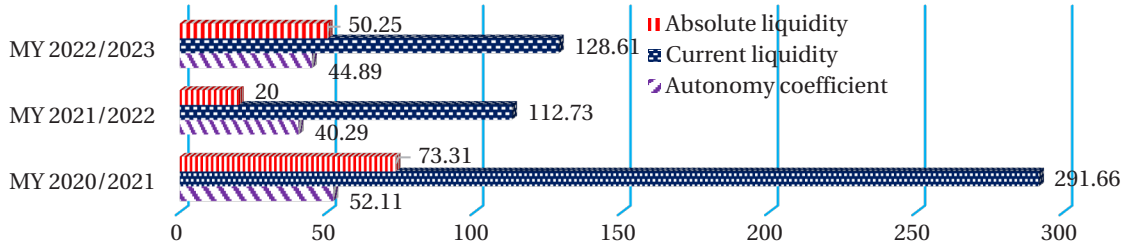

Figure 12. Dynamics of changes in absolute and current liquidity, autonomy ratio in Kernel Holding S.A., %
Source: Kernel Holding S.A. Annual report (2023)

The study of the theoretical and methodological foundations of functioning and survival of large entrepreneurial structures in rural areas in crisis conditions is a common problem. The analysis of the trends in the development of integration associations of farms and agroholdings in the agricultural business confirms their special importance as those that timely adapt to any changes in the market environment in extreme conditions of functioning. The issues of development of integration structures in agriculture are considered in different interpretations in scientific and methodological publications.

The authors of the current study agree with the position of the scientist O. Khytra (2022), who reveals the role of integration synergy as an effect of combining the potentials of business entities in the spatial and temporal combination of agricultural production resources. The authors of the current study agree that mergers (or acquisitions) make it possible to increase the competitiveness and adaptability of functioning, reduce the level of costs and increase the value of the integrative association, and expand the capacity of the market niche in the environment. H. Mazur (2022) studied the experience of stimulating the development of cluster structures, accelerating the integration processes of business entities, implementing cluster adaptation processes in the system of development of agro-food regional cluster associations, and proposed the structure of the region's food security cluster on the basis of providing citizens with

high-quality organic agricultural products and an infrastructure system for business support. A group of scientists A. Sumets *et al.* (2022) identified the components of the mechanism for managing environmental risks of business entities in agriculture in accordance with the functions, goals, methods, object, and subject of management; the functional and process essence of the links between the elements of the environmental risk management system and the multicriteria variability of choosing a solution to the problem are substantiated. On the positive side, the use of modelling methods for preventing environmental risks of agricultural holdings makes it possible to increase the share of organic products in the market environment; to increase the competitiveness of large business entities and access to EBRD loans or funds from grant programmes. In their study, H. Kaletnik *et al.* (2022) focused on the development of agricultural cooperatives as the most capable integration formations and a sustainable form of economic organisation in the renewable energy system. They agree that as a result of the entrepreneur's participation in the activities of an energy cooperative, the socio-economic benefits of the business entity's business in agriculture increase due to the growth of the added value of its products.

Also, R. Bezus & L. Kriuchko (2022) substantiate the need to intensify the creation and development of agricultural cooperatives based on medium, small or small producers in the market environment, which will qualitatively improve the efficiency of marketing and logistics activities of micro, small and medium-sized agricultural businesses. It should be emphasised that official state statistical sources do not contain information on the state of implementation of information and communication technologies or digital marketing tools for business entities in agriculture. A. Semysal (2022), in the process of studying the development of cooperative relations in dairy farming, found that in the current crisis conditions, the functioning of dairy cooperatives without ensuring their competitiveness and state support is impossible. The team of authors V. Lavruk *et al.* (2022) substantiated the expediency of establishing agricultural service dairy cooperatives in the system of separate servicing of dairy cows of households. The authors of the current study support the position of scientists that in order to increase the volume, quality and competitiveness of milk, increase the efficiency of purchase prices for milk, it is necessary to stimulate the socio-economic mechanism for the development of agricultural cooperatives.

The authors of the current study agree with the conclusions of I. Kryukova *et al.* (2023) regarding the margin of safety and strength of the system of functioning of business entities in agriculture in wartime and sustainable agricultural development. Scientists O. Halytskyi *et al.* (2023) revealed the conditions for strengthening the development of the resource potential and competitiveness of agricultural business entities (optimisation of management decision-making, sustainable socio-economic development, digitalisation, intensification of investment and innovation activities; infrastructure restoration; counteracting human resource migration and complications of product exports, etc.). S. Kucherenko *et al.* (2023) found that the process of ensuring guarantees of competitiveness reflects the need to achieve the highest liquidity and solvency of working capital; information and analytical support for business development; improving the quality of operational and strategic planning; preservation of property; modelling the capital structure; optimising the use of aggregate resources; and compliance with environmental standards. Z. Koval (2023) assessed the strategic capabilities of business entities in extreme operating conditions, which help to avoid external threats to the market environment. The authors agree that the use of economic and mathematical modelling allows assessing the available resources of the enterprise and the likely challenges of the environment, as well as scenarios for adapting strategic planning to external threats.

In the course of their research Yu. Sahachko *et al.* (2023) proved that small entrepreneurship is the driving force behind the development of socio-economic and integration relations in the agri-food sector of the economy. Ye. Lanchenko & V. Ivchenko (2023) focus on the mechanisms for stimulating the development of small forms of rural management, in particular, on the efficiency of the functioning of individual entrepreneurs, farms and small businesses in the context of armed conflict. It is emphasised that the intensification of the development of small businesses contributes to solving the issues of unemployment, migration of internally displaced persons, food supply, etc.

O. Shpykuliak *et al.* (2023a) focus on the activities of integrated associative-type formations. The authors of the current study agree with the position of scientists that the development of the institution of self-regulation is an effective incentive to increase the added value of products; reduce transaction costs, direct public expenditures for the implementation of regulatory functions and the social cost of regulation. N. Klymenko *et al.* (2023) assessed the investment attractiveness of agriholdings and analysed the impact of shock risks on the restoration of their capitalisation. It was found that 56% of Ukrainian agriholdings have an insufficient level of capitalisation to fully restore their capitalisation, although all agriholdings overcame the shock period. O. Chorna & K. Sbitnieva (2023) prove that the stable development of rural areas in wartime is linked to the level, state and trends in the development of corporate social responsibility of agricultural holdings, social, environmental and humanitarian responsibility projects, innovative strategies to support the local population, and actions to restore areas affected by military aggression. I. Kytsyuk & I. Kovalchuk (2023) focused on the trends in the functioning of the European Clusters Alliance, on the peculiarities of the formation and development of the Ukrainian Clusters Alliance (founded on 24.05.2022) as a nationwide and multisectoral union of entrepreneurs seeking to develop digital technologies, industrial innovations; create a favourable investment and innovation climate; improve the culture of doing business; increase their own adaptability, sustainability, solvency, independence, liquidity and competitiveness as business entities. The driving force behind "Ukrainian Clusters Alliance" is the Association of Industrial Automation Enterprises of Ukraine.

In addition, the authors of the current study confirm the conclusions of a group of scientists S. Stender *et*

al. (2024), who, in the process of studying the factors and ways to improve the sustainability and productivity of business entities in agriculture, have focused on intensifying the use of such a strategic tool as a digital transformation system. The implementation of innovative approaches in the management decision-making system, in particular, blockchain technologies, contributes to positive changes in the supply chain, increasing the resilience of business entities to changes in climatic, social, economic, and environmental conditions. Y. Danko & D. Zhyvytskyy (2024) substantiate that an effective tool for increasing the competitiveness of business entities and production productivity, attracting investment, stimulating the development of cooperative associations, rural areas, infrastructure development, innovative growth, and diversification of production is the creation and functioning of dairy clusters. O. Zhylinska & N. Sviderska (2024) also reveal the peculiarities of increasing the effectiveness of the implemented organisational tools in the marketing system of business entities and provide recommendations to entrepreneurs in order to meet modern marketing needs.

Noteworthy are the results of the study by O. Vitryak & V. Tkachuk (2024), which emphasises the role, status and trends in the development of private farms and family farms, taking into account the experience of entrepreneurs in the USA, Canada and France. O. Poleva & V. Gavrilyuk (2024) reveal the process of reproduction and activation of the production potential of farms in wartime. The authors of the current study also support the results of the research of O. Skydan *et al.* (2024), which proves that the functioning and development of business entities in agriculture on the basis of constant and systematic growth of gross value added reflects the use of the EU experience. The authors emphasise the use of cybernetic modelling for management in the system of entrepreneurship in agriculture, taking into account the positions of increasing gross value added. V. Kyfyak & R. Dubinskyi (2024) identified the main fluctuations in the impact on the development of business entities: a) fluctuations in the hryvnia exchange rate, prices for agricultural products in foreign markets, socio-political crises and armed conflicts; b) loss of human resources; destruction of equipment and infrastructure). Researchers M. Melnyk & I. Leshchukh (2024) have revealed the characteristics of spatial integration based on agglomeration from the perspective of institutional support for balancing the interests of territorial communities, the main directions for formation (overcoming socio-economic disparities in spatial development; substantiation of mechanisms for stimulating and forms of spatially integrated economic development, promoting inter-municipal cooperation, implementing a system of public-private partnerships; developing priorities for smart specialisation of territories) and strategic priorities for integrated spatial development in extreme conditions of operation and post-war reconstruction.

Scientists S. Bilous & A. Bryvus (2024) relate the adaptation of agricultural production under conditions of martial law to the adequacy of changes in production processes to specific needs or to a reorientation towards the production of different goods. The resilience of production is ensured by timely reorganisation of business processes. Therefore, from the perspective of these scholars, adaptability is essentially the ability to respond promptly to changes or to adjust to them. Researcher O. Toporkova *et al.* (2022), S. Kravchenko *et al.* (2024) substantiate that the adaptation processes of entities in large, medium, and small enterprises within agriculture are linked to the development of strategies for entrepreneurs to counter the impacts of extreme operational conditions and the challenges of Euro-integration. Scholars N. Heorhiadi & A. Kubant (2024) established in their research that the adaptability of the management system of an entrepreneurial entity in agriculture reflects the ability to make timely changes to activity plans. It is emphasised that systems of crisis, conflict, innovation, leadership, project, ecological, and strategic management are adaptive, as they possess flexibility in planning and execution; identification of threats; management of attitudes towards change; flexibility and responsiveness to changes; monitoring and feedback; minimisation of harm, and others.

It has been established that agricultural holdings (vertically integrated structures that contribute to increasing the adaptability, resilience, and competitiveness of large-scale production, the stability of supply chains, and the minimisation of costs) and agricultural cooperatives (horizontally integrated structures that promote the well-being of peasants, the viability of small agricultural producers, and the enhancement of their survival potential in a market environment under extreme operating conditions) are the most common integration structures in the agricultural sector of the economy. The conceptual platform for formulating the development strategy of integration structures is based on a systematic-functional approach with an integrative comprehensive assessment of resource potential, influencing factors, trends in agricultural development, and the specifics of the agro-industrial state of agricultural business.

▸ Conclusions

It is substantiated that employment issues in rural areas can be addressed through the development of integrative structures and associations of farm enterprises. The development of integrated entrepreneurial structures is based on their function – addressing the socio-eco-economic problems of their entrepreneurial subjects. The main obstacles to activity include export difficulties, logistics, pricing, and financial issues. Only united entrepreneurial structures can function effectively and productively. This is also corroborated by the socio-economic indicators of the development of individual large entrepreneurial structures. To create conditions for the productive development of integrated entrepreneurial structures, it is necessary to: improve integration institutions (regulating integration legislation); establish a platform for the development of clusters and cooperatives (developing entrepreneurial subjects, family farms); take into account the experience of other countries for the purpose of comparing legislative frameworks; implement integration diplomacy (connections with foreign institutions); assist investors in information and consulting support; ensure predictability in agricultural policy; control the registration of integration associations, etc. It is essential to develop programmes for the development of cooperative associations of family

farms in the regions for the period up to 2030. The practical significance of the research lies in assessing the state of development of integration processes and the activities of individual large entrepreneurial structures. In further research, it is necessary to specify the main organisational and economic principles of the development of integration structures and cooperative associations in the context of post-war transformations.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Розвиток інтеграційних структур в аграрному секторі економіки в умовах воєнного часу

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► **Анотація.** Активізація діяльності інтеграційних структур має особливе значення в системі нарощування платоспроможності, конкурентостійкості та адаптивності аграрного сектору економіки, стабілізації продовольчої безпеки в умовах інтеграції із європейською спільнотою. Мета статті було обґрунтувати теоретико-методологічні, соціально-економічні засади, проблеми розвитку інтеграційних структур на селі в екстремальних умовах діяльності. За методологічну основу дослідження слугували положення сучасної інституціональної економічної теорії, функціонального та системного аналізу. Використано монографічний, економіко-статистичний, графічний, структурно-функціональний та абстрактно-логічні методи та підходи узагальнення результатів. Розглянуто сучасний стан, місце і роль інтеграційних структур. Проведено системний аналіз проблем і тенденцій функціонування інтеграційних структур в період воєнного часу. Розглянуто теоретико-методологічні аспекти функціонування інтеграційних формувань. Виявлено причини, що гальмують активізацію інтеграційного руху в аграрній сфері економіки на сучасному етапі розвитку. Оцінено динаміку розвитку діючих великих підприємницьких структур в Україні та виявлено негативні аспекти, які необхідно враховувати при організації та функціонуванні інтеграційних об'єднань в залежності від виду та діяльності об'єднання. З'ясовано роль міжнародної технічної допомоги та державної підтримки в стимулюванні та стратегії розвитку інтеграційних структур в Україні. Виявлені можливості та перспективи розвитку інтеграційного руху та проблеми стабільного розвитку інтеграційних структур. З'ясовано, що одним з пріоритетних напрямів регіональної політики є розвиток інтегрованих формувань агрохолдингового типу та кооперативних структур на селі. Розкрита роль інтеграційних структур у формуванні соціального капіталу та сталому розвитку сільських територій в післявоєнній відбудові економіки України. Інформаційний матеріал можливо використовувати при розроблені програм розвитку великих підприємницьких структур в аграрному бізнесі регіонів

► **Ключові слова:** суб'єкт підприємницької діяльності; підприємницькі структури; інтегровані формування; аграрний бізнес; агрохолдинг; кооператив

Received: 07.09.2024. Revised: 24.01.2025. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.28

Ekonomika APK, 32(2), 28-38

UDC 631

Financing of agricultural enterprises in times of war as a guarantee of sustainable development of the state economy

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▸ **Abstract.** The stable and efficient development of agricultural enterprises is an important factor in supporting the national economy, as they contribute to economic stability not only in the short term but also create long-term benefits for the country. The purpose of this study was to analyse the financing of agricultural enterprises in the context of the war in different regions of Ukraine, in particular, to examine the available financial mechanisms and their impact on the resilience of the agricultural sector in the western, central, eastern and southern regions. The study focused on the financing of agricultural enterprises during the war and its impact on the stability of Ukraine's agricultural economy. The authors examined various sources of financing, such as government programmes, international assistance and private investment, which provide support to the agricultural sector in times of crisis. Based on the analysis of available financial mechanisms, it was found that concessional loans, grants and state subsidies are important tools for restoring production, preserving jobs and developing rural areas. Regional differences in access to finance were analysed, and it was found that the western and northern regions have better opportunities to attract international assistance, while enterprises in the eastern and southern regions face greater difficulties. The authors offered a number of recommendations for improving financial mechanisms, including expanding access to soft loans and grants and creating transparent conditions for attracting investment. The study has shown that effective financial strategies and government support are key to the recovery and development of the agricultural sector, which in turn will contribute to the overall economic stability of Ukraine in the context of the war

▸ **Keywords:** industry; innovation; economic growth; food security; Ukrainian regions

▸ **Suggested Citation**: Kryshtal, H., Bezhenar, I., Khimich, S., & Skyba, H. (2025). Financing of agricultural enterprises in times of war as a guarantee of sustainable development of the state economy . *Ekonomika APK*, 32(2), 28-38. doi: 10.32317/ekon.apk/2.2025.28.

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▸ Introduction

In today's world, which is facing various crises and economic challenges, agricultural enterprises are becoming key to achieving Ukraine's sustainable development goals. First of all, agricultural enterprises ensure food security of the country, act as a stable source of state budget revenues and create conditions for efficient use of the production and economic potential of the national economy. The sustainable and efficient development of agricultural enterprises is crucial for supporting the national economy, as they provide stability not only in the short term but also generate long-term benefits for the country. However, to achieve stability, it is necessary to provide enterprises with sufficient financial resources and optimise the financing structure, which includes own, borrowed and debt funds. The unique features of the agricultural sector determine the specifics of financing management, as the industry is subject to seasonal risks, climate change, and requires significant investments in production upgrades, logistics development, and innovation. Thus, the stable development of agricultural enterprises is the basis for the formation of sustainable social and economic processes, as it helps to maintain a balance in the labour market, promotes the development of related industries, and supports local communities. Expanding financial capabilities and improving management efficiency in the agricultural sector creates the basis for building an economy that can adapt to external and internal challenges, which is critical in times of war.

J. Du *et al.* (2020) focus on how to use evolutionary games to model the interactions between different actors in the agro-industrial complex (e.g. farmers, producers and consumers) seeking to achieve sustainable production practices. They analyse how intensive management practices affect decision-making on the transition to green production methods, based on collective behaviour and network structures. O. Bazaluk *et al.* (2020) explore opportunities for agricultural sector development through organic farming. The results of the research can help identify areas for attracting investment and financing for agricultural enterprises in times of war, emphasising the potential of organic production as a tool for sustainable economic development, even in difficult conditions. Researchers M.M. Mia *et al.* (2022) studied the impact of green entrepreneurship on social change, as well as the factors influencing the AMO (Ability, Motivation, Opportunity) theory, analysed the role of environmental entrepreneurship in development and the impact on socio-economic processes. This study suggests approaches to integrating sustainable and environmentally responsible business models into the agricultural sector, which may be important during the post-war recovery, when sustainable development is of particular importance.

At the same time, scientist O.L. Chibuzor (2020) describes a comprehensive assessment of the competitiveness of agricultural enterprises, analysing the key factors that affect their success in a competitive environment. The author develops a methodological approach for assessing competitiveness, which includes financial, production, marketing and management indicators. In addition, he examines the impact of internal and external factors on the efficiency of enterprises and emphasises the importance of innovation and sustainable practices in achieving competitive advantage in the agricultural sector. Y. Liang (2021) focuses on the factors that can lead to errors in financial reporting, such as the complexity of accounting for biological assets, seasonality of income, changes in product prices, and financial pressures. The author also discusses methods of identifying and managing the risks of misstatement, emphasising the importance of effective internal controls and transparency to improve the reliability of financial information of agricultural enterprises.

In their work, W.B. Morgan & R.J.C. Munton (2023) studied the interaction between enterprises and systems, focusing on how organisations function within complex economic and governance systems. The authors analysed different types of systemic approaches to enterprise management, including adaptive, cyber-technological and ecologically oriented models. They also examined how a systems approach contributes to improving management efficiency, optimising resources, and innovating, especially in the context of modern digitalisation and global challenges. D. Škodová Parmová & J. Novotná (2022) analysed quality management methods and tools, as well as approaches to innovation that contribute to productivity, optimisation of production processes and sustainable development. Their study focuses on examples of successful innovation, as well as barriers to innovation, such as lack of funding, low technological awareness and the need for specialised personnel.

At the same time, M. Tang & Z. Wang (2021) apply fuzzy multicriteria analysis to evaluate agricultural product logistics in the management of the agricultural economy. The authors investigate how fuzzy analysis techniques can help to account for uncertainty and subjective factors in decision-making regarding the transport, storage, and distribution of agricultural products. They analyse various criteria such as efficiency, cost, delivery time and quality of service to help optimise supply chains, increase productivity and provide greater flexibility in responding to changing market conditions. O. Latysheva *et al.* (2021) studied the management of sustainable development of machine-building enterprises through the sustainable space development approach, focusing on innovation, resource efficiency and development strategies in a changing environment. Sustainable development methods used in mechanical engineering can be adapted for the agricultural sector, in particular to optimise resources and financing in times of crisis and war.

Given the significant achievements in the study of the development of agricultural enterprises and agroeconomics, it can be argued that the study of financing of agricultural enterprises in war is extremely relevant. In the face of global challenges, such as economic crises, political instability and, in particular, war, the agro-industrial complex is becoming not only the main source of food security, but also a key element for stabilising the economy of a state. Financing agricultural enterprises during this period is key to their ability to adapt to new realities, maintain production capacity and maintain employment in rural areas. Investments in the agricultural sector

promote innovation, modernisation of technologies and improved management practices, which in turn increase productivity and competitiveness. In addition, ensuring adequate financing in times of war helps to mitigate risks and losses that may arise from supply disruptions, reduced demand or increased costs of raw materials. This underscores the importance of creating financial mechanisms that can support agricultural enterprises in times of crisis, including government programmes, soft loans, grants and other instruments. Thus, the main purpose of the article was to study the topic of financing agricultural enterprises in times of war as a guarantee of sustainable development of the state's economy and to formulate effective solutions to support agricultural enterprises in Ukraine in times of war.

▸ Materials and methods

The study used a wide range of information sources, including scientific publications, official reports, statistics, analytical reviews, as well as materials from international organisations and financial institutions. Particular attention was paid to research on the mechanisms of financing agricultural enterprises, their adaptation to crisis conditions, in particular as a result of the war, and the prospects for sustainable development. The main sources included official statistics provided by the State Statistics Service of Ukraine (n.d.); scientific articles published in international and national journals. The study covered the period from 2021 to 2023 in terms of financing of agricultural enterprises in Ukraine, focusing on the crisis conditions, in particular the war, which affected the agricultural sector of Ukraine. Due to limitations in statistical information, the study used only aggregated data by region, which allowed to assess general trends without disclosing confidential data of individual companies, as this could lead to a potential conflict of interest or affect the competitive environment of the industry. In addition, at the time of publication, the official website of the U.S. Agency for International Development (USAID) (n.d.) was not functioning, so the article provided a link only to the main page of the website, and not to individual programmes funded by this organisation. To analyse the financing of agricultural enterprises during the war, Ukraine was divided into four regions: western, central, eastern and southern. The study was based on the financial performance of specific enterprises and their changes before and during the war. The analysis included processing statistical data, identifying trends, and comparing across regions.

The study applied econometric modelling, which was used to forecast the financial results of agricultural enterprises based on the analysis of historical data, assessment of the efficiency of financing and identification of the main trends in the development of the industry. This method allowed not only to assess the current financial condition of enterprises, but also to develop forecasts for their further functioning in the crisis, taking into account macroeconomic and sectoral risks. The case study method was also used, which involved a detailed study of the activities of individual enterprises, allowing for a deeper understanding of the impact of financing, government support, investment attraction and crisis conditions on their operations. The analysis of specific cases helped to identify key factors affecting the financial sustainability of agricultural businesses in difficult economic circumstances, as well as to identify effective strategies for adapting enterprises to changes in the external environment. The results obtained allowed to formulate practical recommendations for improving the financial capacity of agricultural enterprises, ensuring access to financial resources and preparing for possible future crises. This approach allowed not only to assess the current state of agricultural enterprises, but also to develop practical recommendations for ensuring that agricultural enterprises receive financing to ensure their sustainable development.

▸ Results and discussion

Studying the financing of agricultural enterprises in times of war is an important aspect not only for the development of the agricultural sector, but also for the stability of the country's economy in times of crisis. Analysing the current state of the financial potential of agricultural enterprises, it was found that one of the key obstacles to its effective development is systematic disruptions in the financing of economic entities. This negatively affects not only their financial stability but also the overall level of competitiveness in the agricultural sector. To solve this problem and significantly increase the financial potential of agricultural enterprises, it is necessary to focus on several critical tasks.

First, expanding the range of financial resources is an integral part of successful financial management. Agricultural enterprises should use a variety of sources of financing, such as government subsidies, loans, investments from private and international organisations, and alternative financial instruments such as crowdfunding (Loi, 2023). Attracting new sources of finance will allow farmers not only to reduce their dependence on traditional bank loans, but also to take advantage of more favourable conditions on the market.

Second, increasing the revenue side of the enterprise's budget is critical for its financial stability (Vynogradnya & Burdonos, 2021). This can be achieved by optimising production processes, introducing new technologies that increase productivity, and expanding markets. It is also important to focus on improving product quality, which will help to obtain higher prices on the market. Investing in marketing and advertising, as well as in research and development, can be crucial to increasing demand for an agricultural enterprise's products.

Third, optimising the company's costs should be a priority. This includes not only reducing the cost of raw materials, energy and other resources, but also adopting more efficient management practices. Implementing a cost management and financial analysis system will help identify inefficient costs and find ways to reduce them. Additionally, considering energy saving opportunities and implementing environmentally friendly technologies can reduce costs and improve the reputation of the enterprise among consumers. The results of the analysis of the financing of agricultural enterprises in Ukraine during the war are presented in Table 1.

Table 1. Financial indicators of the agricultural sector by regions of Ukraine (2021-2023)

Region	Year	Gross revenue, UAH million	Net profit, UAH million	Return on assets (ROA), %	Accounts payable, UAH million	Number of employees (average)	Export deliveries, UAH million
Western	2021	2,800	350.0	12.5	600	10,000	1,200
	2022	2,500	300.0	12.0	650	9,500	1,000
	2023	2,100	210.0	10.0	700	9,200	850
Central	2021	5,400	620.0	11.5	1,100	20,500	2,500
	2022	4,800	500.0	10.4	1,300	19,800	2,000
	2023	4,200	320.0	7.6	1,400	19,000	1,700
Eastern	2021	1,200	80.0	6.7	250	5,500	600
	2022	900	20.0	2.2	280	3,500	300
	2023	450	-50.0	-4.5	300	2,000	100
Southern	2021	1,500	100.0	6.5	400	6,000	700
	2022	1,000	10.0	1.0	450	4,000	300
	2023	500	-60.0	-5.2	500	2,500	50

Source: prepared on the basis of research data by the State Statistics Service of Ukraine (n.d.)

In 2021-2023, the eastern and southern regions will see the largest decline in gross revenue and net profit, driven by active hostilities, infrastructure destruction and limited access to logistics routes. At the same time, the western region is better able to adapt to the war due to its proximity to European markets, a more stable security situation and continued export opportunities. Despite significant losses, the central region retains its leadership in terms of absolute gross income and profitability, which is explained by the developed infrastructure, production scale and relatively safe location of most agricultural enterprises.

In addition, it is important to consider the social aspect of agricultural enterprises. Interaction with local communities, support for social programmes, and environmental responsibility can strengthen the reputation of agricultural enterprises and increase their sustainability in the long run (von Kaufmann & Skafida, 2023). As a result of these objectives, agricultural enterprises can not only improve their financial potential but also make a significant contribution to the sustainable development of the agricultural sector in the face of current challenges. To achieve successful financing of agricultural enterprises, a comprehensive approach is needed, including innovative solutions, effective management strategies, and active cooperation with all participants in the agricultural process (Wezel *et al.*, 2020). This will not only overcome the existing financial difficulties, but also create the basis for the sustainable development of the agricultural sector as a whole.

The financial potential of agricultural enterprises directly depends on the efficiency of attracting and using financial resources, which is a critical aspect for the stability and development of this industry. When the level of efficiency of financial resources management decreases, it negatively affects the overall financial potential of the enterprise. Therefore, in order to stabilise and improve this potential, it is necessary to focus on balancing the indicators of attracting and spending finance. Improving the efficiency of financing of agricultural enterprises can significantly affect their ability to grow and adapt to current economic challenges. The key point in this process is to analyse the structure of financial resources of agricultural enterprises. In particular, it is important to examine the proportions between equity and debt, as this information can reveal potential risks to the financial security of the enterprise. An incorrect ratio may lead to the financial inability of the enterprise to cope with crisis situations, which in turn will negatively affect its stability and competitiveness.

It is also necessary to emphasise the importance of monitoring the sources of financing, which can significantly affect the financial sustainability of agricultural enterprises. Enterprises should actively analyse their financial flows and regularly evaluate their efficiency. This includes both internal and external sources of funding, such as banks, investment funds, government support programmes for the agricultural sector and other mechanisms. Only through careful analysis and planning can agricultural enterprises identify the most efficient and profitable sources of financing that will help them achieve their strategic goals. However, it is important for agricultural enterprises not only to find optimal sources of financing, but also to manage the risks that may affect their financial potential. This involves conducting a detailed financial analysis, assessing possible threats and taking measures to minimise them.

Thus, improving the process of financing agricultural enterprises is an integral part of the strategy of increasing their financial potential. This requires a comprehensive approach that includes optimising the structure of financial resources, monitoring and managing risks, and regularly analysing financial performance. Ultimately, such efforts can contribute not only to improving the efficiency of individual enterprises, but also to the development of the agricultural sector as a whole, which, in turn, will ensure economic stability and sustainable development of the country in the face of current challenges.

In today's challenging environment of Ukraine's financial system, characterised by economic challenges, instability and military operations on its territory, attracting additional credit resources for agricultural enterprises is becoming extremely important. However, this decision requires careful analysis, as responsible management of financial resources is a key factor in ensuring the sustainability and development of the agricultural sector. In order to make an informed decision on the feasibility of expanding lending, it is necessary to conduct a detailed

diagnosis of several key aspects of the financial security of an agricultural enterprise. First, the probability of an enterprise's bankruptcy should be assessed, which allows identifying potential risks associated with its financial stability. For this purpose, it is advisable to use bankruptcy assessment models, in particular the modified Altman model, which has proven itself in practice (Sumets *et al.*, 2022). This model allows for a comprehensive analysis of the company's financial indicators, such as the ratio of equity and debt, asset liquidity, profitability and turnover, which together will help to form a picture of the financial health of the agricultural enterprise.

The next important block is the liquidity of economic activity. Liquidity indicates the ability of a business to quickly turn assets into cash to cover short-term liabilities (Yadav *et al.*, 2022). A low level of liquidity may indicate problems in financing current operations, which may jeopardise its ability to meet obligations to creditors. The liquidity assessment should include an analysis of the ratio of short-term assets to short-term liabilities, which allows identifying potential problems and taking timely measures to eliminate them. In addition, it is important to determine the share of borrowed capital in the structure of the company's funding sources. This helps to understand the extent to which the company relies on external financial resources and how this affects its financial independence and sustainability. A high level of borrowed capital may increase risks for the enterprise, as dependence on creditors may lead to limited manoeuvre in financial management.

The last but not least aspect is the solvency of a business entity. This indicator reflects the company's ability to meet its financial obligations in a timely manner. Solvency analysis involves examining the ratio of short-term assets to short-term liabilities, which can give a clear indication of the extent to which a company is able to cover its debts. Before making a decision to expand the amount of financial resources through borrowed funds, it is necessary not only to conduct a detailed analysis of the above blocks, but also to take into account external factors such as the economic situation in the country, political risks and changes in legislation that may affect the activities of agricultural enterprises. Only a comprehensive analysis can help formulate a strategy that will ensure the growth of the financial potential of an agricultural enterprise in the face of modern challenges. In order to ensure efficient business operations, agricultural enterprises must actively attract additional resources, which is crucial for maintaining their operations in a constantly changing environment. Raising funds will not only cover the costs of the sowing campaign, but also ensure an appropriate level of technological development, which in turn will affect the productivity and quality of the products.

Taking into account the prospects for the development of the agricultural sector, especially given the important role of small and medium-sized businesses as the backbone of this segment of the economy, banks offer a variety of financial products for agricultural businesses. In particular, the "5-7-9" programme, which aims to support farmers by providing low-interest loans, allows SMEs to obtain financing on favourable terms. In addition, preferential partnership programmes are being developed to enable farmers to obtain additional resources to cover production costs. The use of commodity bill avalisation opens up new horizons for farmers in raising working capital, while grants and local support programmes provide additional opportunities for financing investment projects (Ministry of Agrarian Policy and Food of Ukraine, 2025). Cooperation with international partners in financing the agricultural sector is becoming increasingly important. International organisations are ready to provide financial and advisory support, which allows agricultural producers to implement projects aimed at modernising and introducing new technologies. This, in turn, can significantly increase the competitiveness of Ukrainian farmers on international markets.

To summarise, effective financing of agricultural enterprises is a key element for ensuring their resilience and development in times of war. The availability of a variety of financial products tailored to the needs of farmers is key to ensuring the sustainable development of Ukraine's agricultural sector (Shpychak *et al.*, 2022). Therefore, it is important that farmers actively use these opportunities to ensure the country's food security and economic recovery. The financial support of agricultural enterprises, in turn, is based on a wide range of sources. This structure includes both own financial resources of enterprises and external financial liabilities, which include long-term loans, current liabilities and various other forms of collateral.

The company's own funds, such as profit, depreciation and other internal reserves, are the foundation for its operations and further development. However, in the context of limited funding and the need to expand production, agricultural enterprises are forced to turn to additional sources of capital. Among these sources, long-term loans play an important role, as they are granted for long periods of time and allow enterprises to invest in modernisation, expansion of production, and purchase of new technologies and equipment. Long-term liabilities provide enterprises with a stable flow of financial resources for strategic purposes, which is especially important in the agricultural sector, where production cycles depend on the season and external factors.

Short-term liabilities, in turn, are a source of funding to cover the current needs of the company. They include working capital loans, short-term borrowings, accounts payable and other instruments that help to maintain the liquidity of the enterprise at an appropriate level. Current liabilities are important for ensuring the smooth running of the production process, allowing agricultural companies to purchase raw materials in a timely manner, pay for transport and other operating expenses, which is critical for the successful completion of agricultural operations.

The distribution of sources of financing for agricultural, forestry and fisheries enterprises has its own specifics, which depend on various factors, such as the size of the enterprise, its strategic goals and external business environment. For example, large agricultural holdings are able to obtain loans from commercial banks on much better terms than small farms, and can also attract investment through the issuance of corporate bonds or other capital from the stock markets. At the same time, government support programmes, subsidies, grants, and partnership programmes can play a critical role for small enterprises that have limited access to bank financing (Table 2).

Table 2. Structure of financial sources of agricultural enterprises in Ukraine

Sources of funding	2021	2022	2023
Equity, UAH million	340,145	360,120	375,210
share, %	44.10	43.75	43.50
Long-term liabilities and provisions, UAH million	105,200	112,350	120,980
share, %	13.36	13.65	14.01
Current liabilities and provisions, UAH million	284,920	305,480	320,730
share, %	36.92	37.42	37.25
Liabilities related to non-current assets and pension funds	1,560	1,580	1,590
share, %	0.22	0.18	0.18
Total, UAH million	731,825	779,530	818,510
share, %	100	100	100

Source: prepared on the basis of research data by the State Statistics Service of Ukraine (n.d.)

Thus, a balanced structure of financial sources enables agricultural enterprises to operate efficiently even in the face of economic changes that may be caused by seasonal fluctuations and external factors such as economic instability or political risks. The analysis presented in Table 2 clearly indicates a tendency to change the structure of financial sources of agricultural enterprises, which leads to an increase in the industry's dependence on external financial sources. In particular, the results indicate a gradual increase in the share of current liabilities, which rose from 36.92% in 2021 to 37.25% in 2023. This dynamics is mainly due to an increase in accounts payable, while the volume of bank loans remained stable. This trend demonstrates certain limitations in the financial sustainability of enterprises, which may be a result of insufficient liquidity or banks' restrained attitude to lending to the agricultural sector.

The stable amount of equity capital, which stood at 43.50% in 2023, indicates that companies rely heavily on their own financial resources. However, these indicators need to be optimised, as the growth of current liabilities, in particular in the form of short-term payables, limits the financial stability of enterprises and increases the risk of financial instability. Thus, in order to improve the solvency and financial stability of agricultural enterprises, it would be advisable to increase the share of equity in the structure of financial sources. This would allow enterprises to reduce the level of financial risks caused by their high dependence on short-term external sources and, at the same time, increase their attractiveness to potential investors.

To ensure the financial sustainability of agribusinesses, it is important to increase equity capital, which is one of the key factors of stability and independence from external sources. The basis of equity capital of agricultural enterprises is made up of contributions from the founders, as well as retained earnings generated in the course of successful operations. However, the share of loss-making enterprises in Ukraine's agricultural sector is quite high, which limits their ability to accumulate sufficient own resources for further development. This forces companies to look for alternative sources of funding. Given the difficult financial environment, agricultural enterprises can choose different approaches to financing:

1. Self-financing is a method in which companies use only their own resources. It is important that their share is at least 75-80%, which will ensure stability without the involvement of external creditors and investors. This approach is ideal for financially stable enterprises, but can be difficult for loss-making farms that are unable to quickly build up internal reserves.

2. Debt financing is the attraction of funds from external sources, including bank loans, bonds or financial assistance from investors. It is important that the share of borrowed resources does not exceed 55-60% of total capital, as excessive dependence on loans increases the risk of insolvency and increases debt service costs. This option is particularly attractive for businesses that need quick capital to modernise or expand production.

3. Mixed financing is an optimal combination of own and borrowed financial resources that allows enterprises to maintain a balance between independence and access to additional capital. In this case, the share of own and borrowed funds is almost equal, which allows the company to take advantage of external financing without a significant risk of losing financial stability.

When choosing a particular financing option, it is important to remember that increasing the share of equity contributes to strengthening the financial autonomy of the enterprise, reduces dependence on external sources and ensures long-term stability (Table 3). Table 4 provides an overview of the main programmes, indicating the regions that actively use them and the results of their implementation.

Table 3. Financial support for Ukrainian agricultural enterprises under martial law

Organisation	Programme name	Period	Total cost	Notes
USAID (n.d.)	Agricultural and Rural Development Programme (AGRO)	within 5 years (until 2024)	35 million USD	This programme is aimed at supporting agricultural producers who have suffered significant losses due to the war, helping them to restore production and ensure food security.
USAID (n.d.)	Project "Credit resources for agricultural producers"	within 7 years (until 2023)	8.9 million USD	This project provides credit unions with resources that they can use to provide loans to micro and small farmers, supporting their financial stability.

Table 3, Continued

Organisation	Programme name	Period	Total cost	Notes
USAID (n.d.)	"Sustainable Agriculture Initiative in Ukraine"	-	100 million USD	The initiative is aimed at supporting the export of Ukrainian agricultural products, which is important for improving the economic situation and reducing losses in the agricultural sector.
FAO together with the Government of Ukraine	Humanitarian aid from FAO – temporary grain storage facilities (State Agrarian Register of Ukraine, n.d.)	until 03.11.2022	30,000 pieces of polymer sleeves	Agricultural enterprises receive free polymer sleeves for grain storage, which improves storage conditions and reduces the risk of losses during military operations.
Government of Ukraine	Law of Ukraine No. 2445-IX (2022)	-	-	The law provides agricultural producers with an exemption from import duties on goods required for the storage of grain and oilseeds, which eases the financial burden on farmers.
Cabinet of Ministers of Ukraine	Resolution of the Cabinet of Ministers of Ukraine No. 694 (2009)	-	-	The simplified procedure for registering agricultural machinery facilitates faster renewal of the machinery fleet, which is important for increasing production efficiency in wartime.
Ministry of Agrarian Policy and Food of Ukraine (2023)	State Programme "Affordable Loans 5-7-9%"	-	up to 60 million UAH per agricultural producer	The programme supports farmers who own movable and immovable property by providing them with the opportunity to obtain loans to develop their business and ensure financial stability.
Government of Ukraine (n.d.)	The eRobota programme	12 months for project implementation	no more than 7 million UAH per project	Grants for the construction of modular greenhouses or planting orchards help farmers modernise their production, increasing their productivity and profitability.
EU Delegation in Ukraine (n.d.)	EU-funded support programmes	until 15.11.2022 (the programme was suspended on 16.08.2022 due to a large number of applications)	1 billion UAH	Micro and small agricultural enterprises received financing per unit of cultivated land or livestock, which helped them to restore their production after the war.
European Commission (n.d.)	Subsidy programme for small farmers	2023	80 million USD	The programme provides financial support to small farmers with up to 100 cows or 1 to 120 hectares of land, encouraging them to participate in the recovery of the agricultural sector.

Source: prepared by the authors

Table 4. Use of financial support programmes by agricultural enterprises by region and results of their implementation

Programme	Regions that use	Results
Agriculture and Rural Development Programme (AGRO) (USAID, n.d.)	Western, central, southern	▸ Supporting the recovery of production and food security. ▸ Expanding export opportunities, in particular to the EU. ▸ Increase the efficiency of agricultural enterprises through financial injections and technical support.
Project "Credit Resources for Agricultural Producers" (USAID, n.d.)	Central, western	▸ Providing micro and small agricultural producers with loans to stabilise their financial situation.
Sustainable Agriculture Initiative in Ukraine (USAID, n.d.)	Western, central	▸ Promoting the development of exports of Ukrainian agricultural products, which helped reduce economic losses in the agricultural sector.
Humanitarian aid from FAO (polymeric sleeves for grain storage) (State Agrarian Register of Ukraine, n.d.)	Central, eastern, southern	▸ Improving the efficiency of grain storage, which reduces the risk of crop losses due to wartime conditions.
Law of Ukraine No. 2445-IX (2022)	All regions	▸ Agricultural producers received an exemption from import duties on essential goods for storing grain and oilseeds.

Table 4, Continued

Programme	Regions that use	Results
Resolution of the Cabinet of Ministers of Ukraine No. 694 (2009)	All regions	▸ Simplifying the procedure for registering machinery, which helps to modernise the technical park of agricultural enterprises.
State programme "Affordable Loans 5-7-9%" (Ministry of Agrarian Policy and Food of Ukraine, 2023)	Central, southern, western	▸ Provides farmers with the opportunity to obtain loans for modernisation and development of production.
The eRobota programme (Government of Ukraine, n.d.)	All regions	▸ Increasing the productivity and profitability of enterprises through the construction of greenhouses and gardens.
EU Delegation in Ukraine (n.d.)	Western, central, eastern	▸ Financing for micro and small enterprises to restore production.
Small farmers' subsidy programme (European Commission, n.d.)	Western, central	▸ Providing financial support to small farmers to help them develop their businesses.

Source: prepared by the authors

Thus, a wide range of government and international support programmes are available for agricultural enterprises facing numerous challenges, especially in times of war and economic instability. These initiatives can significantly ease the financial burden on agricultural producers by providing alternative sources of financing that reduce dependence on equity. In particular, support programmes can cover a variety of aspects: from direct subsidies and grants to loans on favourable terms. This allows enterprises not only to sustain their current operations, but also to invest in modernisation, the development of new technologies, and production efficiency. In addition, state support may include educational programmes and consultancy services that promote the development of entrepreneurial skills among agricultural producers. This is important, as good financial management and knowledge of new markets and technologies can be crucial for the success of an enterprise.

Given the specifics of the agricultural sector in Ukraine, government programmes can also be aimed at addressing pressing issues such as product storage, environmental innovations, climate change adaptation and increasing resilience to external economic shocks. This, in turn, contributes not only to the stability of agricultural production but also to the development of rural areas. Thus, the implementation of state and international support initiatives is becoming a key factor in ensuring the economic sustainability and competitiveness of agricultural enterprises in Ukraine. These programmes can greatly facilitate the financing of agribusinesses, stimulating investment and development in this important sector of the economy.

A comparative analysis of the study's results with other works on similar topics allows to identify key aspects that reflect both similarities and differences in approaches and conclusions. In particular, the study conducted by D. Shelenko *et al.* (2023) focuses on the impact of government support programmes for agricultural enterprises in the context of the economic crisis. The authors note that the active involvement of the state in financing the agricultural sector during the crisis can significantly improve the financial stability of enterprises. However, they emphasise the insufficient efficiency of existing lending mechanisms in times of war, which, in their opinion, needs to be revised. The results of the study confirm the opinion of the above-mentioned scholars, but it was found that special attention to the development of investment programmes in sustainable technologies can significantly increase the efficiency of agricultural enterprises in crisis conditions, which was not emphasised in the works of D. Shelenko *et al.*

The paper by V. Kravchenko (2024) analyses the relationship between the financing of agricultural enterprises and the socio-economic consequences for the state in times of war. The author notes that the lack of stable financial resources in countries in crisis situations significantly impairs the ability of agricultural enterprises to adapt to new conditions. It should also be noted that the instability of financing is the main obstacle to the adaptation of agricultural enterprises, but it is additionally proved that the combination of state support programmes with investments in environmentally friendly technologies can improve the situation. The difference between the results of the study and those of V. Kravchenko lies in the emphasis on the importance of innovations in the financing of agricultural enterprises. The analysis conducted by A. Karnaushenko (2020), who also studied the financing of agricultural enterprises in wartime, points to the importance of adapting financial instruments to changing conditions, such as resource shortages, exchange rate volatility, and changes in the market situation. The results of the study partially coincide with the findings of A. Karnaushenko, but it should be noted that for the sustainability of agricultural financing it is also important to take into account the investment component at the level of local communities and enterprises, and not only through national programmes.

In contrast to the results of the study, M. Kryshtanovych *et al.* (2021) investigated the process of building the security potential of engineering enterprises, in particular, focusing on modelling various aspects of security and reliability in the business environment. Nevertheless, the authors demonstrate the importance of security for the stable functioning of enterprises. This study also emphasises that improving security in the agricultural sector can be an important factor for attracting investment and ensuring sustainable development. For a detailed analysis of the definition of this concept, see V. Voronina & R. Spingar (2019).

G.E. Schneider (2021) and A.R. Sayler (2024) analysed current food safety regulations and standards in the US, Canada and Mexico and their impact on the agricultural

sector and food industry, which may be useful for export-oriented agricultural enterprises that need to meet international quality standards. Financing for such enterprises could help them to implement the necessary certifications. L. Lelyk *et al.* (2022) conducted an integrated analysis of the economic security of enterprises, in particular, assessing risk factors and strategies to ensure financial sustainability in difficult economic conditions. Economic security analysis provides an opportunity to understand the key aspects of financial stability and risks faced by agricultural enterprises in times of war, which helps to formulate effective financing strategies. A. Novak *et al.* (2022) analysed financial and economic security in financial markets in the context of European integration, focusing on measures to protect financial interests and stability during the transition to a single economic space. At the same time, J.L. Thomson *et al.* (2024) in their research emphasise the importance of food security, which is a key aspect of sustainable economic development in times of war. Military operations in Ukraine lead to disruptions in the food supply chain, so sufficient funding for the agricultural sector is critical to stabilising the food market.

In general, the analysis of the results of other studies suggests that approaches to the importance of financing agricultural enterprises in crisis conditions, in particular in times of war, are similar. However, the results of the study have some differences, in particular, in focusing on the importance of investments in sustainable technologies that allow agricultural enterprises not only to improve their financial situation but also to adapt to long-term environmental and social challenges.

▸ Conclusions

The study on financing agricultural enterprises in times of war found that government programmes, international assistance and private investment are key to supporting the agricultural sector. This is especially important for enterprises that have suffered significant losses due to the hostilities. The study of financial mechanisms showed that agricultural enterprises can use different financing models depending on their capabilities. In particular, self-financing is suitable for financially stable enterprises, while other models, such as debt financing, are becoming relevant for the recovery of enterprises that have suffered losses.

An analysis of regional specifics showed that the western and northern regions receive more support from international organisations, while in the eastern and southern regions, where the fighting is ongoing, access to funding is much more difficult. This requires special approaches to funding depending on the geographical and economic situation of each region. Based on the findings, a number of recommendations have been proposed to improve the financing of agricultural enterprises, including the need to expand access to concessional loans and grants, especially for enterprises in the affected regions. It is also important to create transparent conditions for attracting investment, which will help modernise production and increase its efficiency.

Overall, the study confirmed that a comprehensive approach to financing is needed to ensure the sustainable development of the agricultural sector in times of war. Only through the support of the state and international partners can agricultural enterprises be restored and strengthened, which in turn will contribute to the country's economic stability. Prospects for further research in this area may include several important areas: assessing the long-term impact of the military conflict on the financial sustainability of the agricultural sector; analysing the effectiveness of existing financial mechanisms to determine how they affect the recovery and development of the agricultural sector; exploring innovative approaches to financing, including agricultural receipts, insurance programmes and crowdfunding, which could be an important step towards improving financial instruments for businesses in crisis.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Фінансування аграрних підприємств в умовах війни як запорука сталого розвитку економіки держави

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► **Анотація.** Стабільний та ефективний розвиток аграрних підприємств є важливим чинником підтримки національної економіки, оскільки вони сприяють економічній стабільності не тільки в короткостроковій перспективі, але й створюють довгострокові переваги для країни. Метою даного дослідження був аналіз фінансування аграрних підприємств в умовах війни в розрізі різних регіонів України, зокрема вивчення доступних фінансових механізмів та їхнього впливу на стійкість агросектора в західних, центральних, східних та південних регіонах. Дослідження було зосереджено на вивченні фінансування аграрних підприємств в умовах війни та його впливу на стабільність агроекономіки України. Авторами в роботі розглянуто різні джерела фінансування, такі як державні програми, міжнародна допомога та приватні інвестиції, які забезпечують підтримку агросектора в кризових умовах. На основі аналізу доступних фінансових механізмів було виявлено, що пільгові кредити, гранти та державні субсидії є важливими інструментами для відновлення виробництва, збереження робочих місць та розвитку сільських територій. Були проаналізовані регіональні особливості доступу до фінансування, і виявлено, що західні та північні області мають кращі можливості для залучення міжнародної допомоги, у той час як підприємства в східних та південних регіонах стикаються з більшими труднощами. Авторами запропоновано ряд рекомендацій для вдосконалення фінансових механізмів, що включають розширення доступу до пільгових кредитів, грантів та створення прозорих умов для залучення інвестицій. Дослідження показало, що ефективні фінансові стратегії та державна підтримка є ключовими для відновлення та розвитку аграрного сектору, що в свою чергу сприятиме загальній економічній стабільності України в умовах війни

► **Ключові слова:** промисловість; інновації; економічне зростання; продовольча безпека; українські регіони

Received: 15.08.2024. Revised: 15.01.2025. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.39

Ekonomika APK, 32(2), 39-49

UDC 338.439.5:338.439.63:634.1.076

Prospects for meeting the needs of the most common types of fruit in Ukraine

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► **Abstract.** During the war, there is a need to provide all market participants with fruit products mainly of Ukrainian production and reduce import dependence. To do this, it is important to establish indicators of the actual level of consumption, general and internal needs in the future, and opportunities for their provision. The purpose of the study was to establish and evaluate the actual fruit consumption fund in Ukraine, considering the food imbalance during the war, and prospective consumption indicators, needs, and possible sources of their coverage. A detailed analysis of the market environment, its changes and mutual influence was based on the balance sheet method, which provided a comprehensive study of the market situation and allowed modelling the economic situation for the future. Correlation and regression analysis techniques were used to determine the prospective parameters of the Ukrainian market. It has been established that in Ukraine the development of fruit supply is carried out in an unorganised manner, given the concentration of their main production in households – by 80%. This leads to differentiation in ensuring consumer demand of the population in the context of regions of the country, by product range and variety, and by place of residence. The main share of fruit production (mainly pome fruits – 90%) is concentrated in the Vinnytsia Oblast (13%). Due to the war, the gross harvest decreased most in Zaporizhzhia, Donetsk, Mykolaiv, Kharkiv, and Dnipro oblasts, which makes it necessary to optimise interregional logistics. The consumption fund is characterised by a

► **Suggested Citation**: Salo, I., Grynchuk, Yu., Svynous, N., Havryk, O., & Grynchuk, K. (2025). Prospects for meeting the needs of the most common types of fruit in Ukraine. *Ekonomika APK*, 32(2), 39-49. doi: 10.32317/ekon.apk/2.2025.39.

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dynamic decline, which resulted in 80.4% of the population's demand for fresh and processed fruit being met. The market capacity covers demand by only 40%, which indicates a high level of natural production and self-sufficiency of the population. In the long term, a slight increase in Ukrainian production, supplies of objectively necessary imports (citrus fruits, bananas), and meeting the domestic needs of the population by 86.8% is expected in 2030. In the future, considering the need to expand industrial intensive horticulture on an innovative basis, for optimal provision of general needs for fruits, state financial support for this type of activity is necessary. The study results should be used in the development of a long-term food supply programme for the short term in the context of optimal provision of fresh and processed fruit products to the population and all market operators

Keywords: production; supply; demand; consumption fund; market capacity; general needs

Introduction

In the current economic development environment in Ukraine, given the war, it is not easy to achieve efficiency in agricultural production, sales, and meeting the needs of all market operators. This is especially true for horticultural products, the cultivation of which is a complex and time-consuming process that requires constant investment in the creation and maintenance of plantings for many years. In this case, the producers will receive a net profit only in a few years when the plantations start bearing fruit. That is, investing in such a business, even without considering possible losses due to the war, is quite risky. In addition, weather conditions, especially changes in climatic conditions, such as drought and heat, have a significant impact on fruit yields. Because of this, the development of the horticulture industry, the Ukrainian fruit market, investment support, supply formation, consumer demand, and needs is of great interest to researchers.

Research of the fruit market, in particular, its parameters of demand, supply, price situation, and the rationality of consumption, the development of internal and external sales channels, the formation of the horticulture industry on innovative principles, investment support for fruit and vegetable regional production are reflected in the papers by L. Yatsyshina (2019), T. Lozova *et al.* (2020) and O. Cherevko *et al.* (2021). Despite the fact that the main share of fruits is produced by households, that is, there are a large number of small producers with small batches of products that mostly do not meet the standards, it is relevant to study the competitive advantages of producers in the fruit market and compare Ukrainian production indicators with the world, establish positions on the international market, which were carried out by I. Kolokolchykova (2019) and N. Rozhko (2020). The profitability of fruit production significantly depends on the speed of their sale through the most efficient channels and storage capabilities, including during transportation. Therefore, it is quite timely to investigate the impact of marketing product policy on the logistics activities of horticultural enterprises, their export potential, which is revealed in the papers by O. Bochko *et al.* (2020) and L. Galat (2021).

Given the limited budget financing of the horticulture industry and in general state support for the development of the Ukrainian fruit market during the war, additional study is required on the issues of fruit production by various categories of farms in modern conditions, the development of a consumption fund, future needs, and sources of their provision. The purpose of the study was to assess the consumer balance of fruits in Ukraine, considering modern economic realities and establishing prospects for ensuring demand and covering needs.

Literature review

Due to the situation that has developed in Ukraine for the period 2022-2024, researchers are increasingly focusing on comparing economic indicators before and during the war. Attention was also focused on the main issue that concerns, in fact, every researcher in Ukraine – what to do in the future for the further development of agriculture on an innovative basis, the agricultural market and, most importantly, the rational provision of the population with the necessary food. Such studies are revealed in the papers by I. Dontsova *et al.* (2022). Thus, the researchers investigated the problems of fruit market development, in particular: reduction of fruit-bearing areas due to military operations in the country, and therefore, gross harvest, crop losses due to late harvesting, increased logistics costs, complexity of transportation and rapid sales, higher prices due to low levels of material support for the population. More detailed analysis of apples, the main fruit in Ukraine in terms of production and processing, was carried out by V. Luzhanskyi (2024). His research focused on the development and evaluation of balance sheet indicators, in particular, the supply and demand of fresh and processed apples and the factors that influence the development of equilibrium of these indicators.

The issue of developing the organic fruit market is becoming increasingly relevant, given the popularisation of healthy nutrition among the population of Ukraine and the world as a whole. Thus, the comparative characteristics of organic agricultural land areas between countries of the world, the development of economic structures engaged in organic fruit cultivation, and, in general, the study of the state of the organic market were carried out by D. Granatstein *et al.* (2016). The active development of organic fruit production, the dynamic growth of operators in this area, and the prospects for further development of organic gardening were noted by I. Horodniak & S. Petrovskyi (2023). They emphasised more specifically that this also applies to processed products.

Processing enterprises serve as an important channel for fruit sales for Ukrainian horticultural enterprises. However, it should be noted that on the one hand, this is a positive phenomenon from the standpoint of the existing possibility of rapid sale of large-scale batches of fruits with excessive crop surpluses and the need for its storage, on the other – negative, since the products are sold at significantly lower prices than for fresh consumption and the owners

get a much lower effect. The issues of fruit processing, in particular, for dried fruits, sweets, sales problems, development of processing enterprises, optimisation of logistics activities and the relationship between processors and direct producers were considered by S. Kierczyńska (2019) and L. Beztelesna & V. Butkevych (2023).

Given that the main share of fruits, which is on average about 85%, in Ukraine is produced by households, the market remains unorganised, with chaotic production volumes and supply. When it comes to entering European markets, it is clear that these manufacturers cannot be competitive by any criteria. When forming a long-term programme for the development of the fruit market, as a rule, all attention is focused on the possibility of expanding production by horticultural enterprises and providing them with state support, including financial support. Only in this way is it possible to ensure the stability of supply and reduce differentiation in the diet of the population. Research on the prospects for the development of industrial fruit and vegetable production, ensuring proper product quality and appropriate prices, export-import supplies of fruits, optimisation of sales was carried out by J. Krykavskyy *et al.* (2021) and L.T. Putri & A. Azhari (2022).

During the period of Ukraine's European integration, studies are relevant and important not only to provide the population with fruit products, reduce import dependence, but also to expand the export potential of horticulture, and the effectiveness of export-import trade. Summarising the results, it should be noted that when forming the Ukrainian product offer in the future, manufacturers should consider consumer demand for organic products, the needs of foreign European markets, product compliance with international standards, and the possibility of diversifying sales channels.

▸ Materials and methods

The variability of the Ukrainian fruit market was manifested in changes in its conjuncture. A detailed analysis of the market environment, its changes and mutual influence was usually based on the balance sheet method, which provided a comprehensive study of the market situation and allowed modelling the economic situation for the future to rationally meet the needs of fruit consumers. The most common methods of correlation and regression analysis in economic research were used to predict the main parameters of the Ukrainian market. The conducted research was based on methodological approaches to determining balance sheet indicators – the total supply and demand of any market of agricultural products and, as a result, the consumption fund.

The research was conducted mainly at the macro level, that is, at the country level. At the micro level, the regional distribution and changes in the structure of production of certain types of fruits before and during the war in Ukraine were analysed. The study used data for the last three pre-war years – 2019-2021 and for comparison indicators during the war for 2022-2023. The paper described the indicators of fruit production (area of fruit-bearing plantings, yield, and gross harvest) in the country and separately by region, consumption (supply, demand, consumption fund, need) and foreign trade (export, import). It is worth noting that in 2022-2023, statistics were provided without considering the territories temporarily occupied by the Russian Federation and parts of the territories where military operations are being conducted.

A step-by-step algorithm for determining the total supply of fruits, total demand, and consumption fund in accordance with the existing methodology, and general and internal needs was established (Letter of the Ministry of Economy and European Integration of Ukraine and the Ministry of Agriculture of Ukraine, 2003):

1. General offer (including commercial and natural output) of the domestic fruit market was defined as the sum of fruit production, import supplies and stocks at the beginning of the year:

$$GO = P + I + Sby, \quad (1)$$

where GO – general offer of fruits, thous. t; P – fruit production, thous. t; I – fruit import, thous. t; Sby – stock at the beginning of the year, thous. t.

2. Total demand (including marketable and natural volume of products) was determined by the equation:

$$TD = GO - Bey, \quad (2)$$

where TD – total demand of fruits, thous. t; GO – general offer of fruits, thous. t; Bey – balance at the end of the year, thous. t.

3. Domestic demand was calculated using the equation:

$$DD = GO - E - Bey, \quad (3)$$

where DD – domestic demand of fruits, thous. t; GO – general offer of fruits, thous. t; E – fruit export, thous. t; Bey – balance at the end of the year, thous. t.

4. Consumption fund was formed exclusively from products that are used for consumption by the population in fresh and processed form:

$$CF = GO - C - L - E - Bey, \quad (4)$$

where CF – consumption fund of fruits, thous. t; GO – general offer of fruits, thous. t; C – fruit consumption in various areas (for feed, seeds, processing for non-food needs, thous. t; L – fruit loss, thous. t; E – fruit export, thous. t; Bey – balance at the end of the year, thous. t.

5. General needs include, in addition to the volume of internal fruit supply (internal needs), the need for fruit processing and export supplies:

$$GN = PN + NP + E, \quad (5)$$

where GN – general needs, thous. t; PN – population needs, thous. t; NP – fruit needs for processing, thous. t; E – fruit export, thous. t.

6. Population needs for fresh and processed fruits were established based on rational norms of consumption of products per person per year, determined by the equation:

$$PN = PS \cdot RC, \quad (6)$$

where PN – population needs, thous. t; PS – population size, persons; RC – rational consumption rate, kg/person/year.

The information base for conducting research was legislative acts, monographs and scientific and analytical publications on the development of agricultural markets, statistics were available on the Official Website of the State Statistics Service of Ukraine (n.d.). Different types of fruits have their own specifics of cultivation, storage, transportation, sale, and pricing, however, the main types of fruit crops were statistically grouped by production, balance indicators, sales, and prices to reveal the economic situation in the country at the macro level. These indicators were also grouped by individual natural and climatic zones and regions to reveal the micro-level situation. For this purpose, the corresponding methods of statistical grouping by State Statistics Service of Ukraine (n.d.) were used. In view of this, when conducting macro-level studies, official statistical indicators for the "fruits" group were used in general and in the context of "fruits of pome crops", "fruits of stone crops", "nuts". A separate group was represented by fruits of objectively necessary imports that do not have a natural growing area in Ukraine.

▸ Results and discussion

In Ukraine, fruits are produced by agricultural enterprises and households. The participation of these categories of farms in the development of market conditions differs significantly. Ultimately, they are different from the standpoint of legislation, and in terms of production and sales volumes, structure and, most importantly, the purpose of their activities. If the main goal of horticultural enterprises is to obtain the highest possible profits from their production activities, then for households it is mainly to provide for their own needs and only then participate in commodity-money relations. For more than a decade, households have been producing the bulk of fruit. Thus, for the period 2019-2023, this is 80-87% of total production volumes or 1,741-2,096 thous. t (Table 1). The main reason that forces these farms to sell fruit products, in addition to the possibility of getting rid of leftovers, especially in too productive years, is the low effective demand of the population. Due to insufficient financial support, especially during the war, the efficiency of horticultural enterprises significantly depends on weather conditions and the ability to establish sales channels for products at the peak of harvest. Ultimately, providing storage facilities for long-term storage of fruits remains insufficient and financially costly, especially if there are no agreements on the effective sale of products in the future.

Table 1. Dynamics of area, yield, gross fruit harvest by categories of farms in Ukraine

Years	All categories of farms	Including			
		agricultural enterprises	in % to all categories of farms	farms of the population	in % to all categories of farms
Area of fruit-bearing plantings, thous. ha					
2019	212	61	28.8	151	71.2
2020	213	59	27.7	154	72.3
2021	171	38	22.3	133	77.7
2022	153	28	18.2	124	81.1
2023	150	29	19.6	121	80.4
Yield, t/ha					
2019	81.4	37.1	45.6	99.3	122.0
2020	81.7	38.3	46.9	98.4	120.4
2021	12.3	11.8	96.1	12.4	101.1
2022	12.2	12.2	99.5	12.3	101.0
2023	12.5	13.0	103.9	12.4	99.0
Gross harvest, thous. t					
2019	1,722	227	13.2	1,495	86.8
2020	1,741	226	13.0	1,515	87.0
2021	2,096	449	21.4	1,648	78.6
2022	1,871	339	18.1	1,532	81.9
2023	1,875	381	20.3	1,494	79.7

Source: calculated by the authors based on State Statistics Service of Ukraine (n.d.)

The regional structure of fruit production in Ukraine is significantly different. Moreover, it has changed due to the war in the country, the loss of plantations, the retirement of old orchards from commercial fruit bearing, and the almost absent establishment of new orchards. Changes in the regional structure of fruit production before (2021) and during (2023) the war, including pome and stone fruits and nuts, are described in Table 2.

Table 2. Structure of production of the main types of fruits by regions of Ukraine, %

Oblasts	Fruits		Pome fruits		Stone fruits		Nuts	
	2021	2023 *	2021	2023 *	2021	2023 *	2021	2023 *
Vinnytsia	12.5	13.4	16.6	16.9	3.2	4.5	3.7	7.2
Volyn	1.7	1.9	1.9	2.1	1.5	1.7	1.1	1.1
Dnipro	6.7	5.9	6.0	5.0	8.0	8.3	9.3	7.2
Donetsk	4.0	1.3	2.6	0.7	7.1	2.7	7.8	2.6
Zhytomyr	1.8	2.0	2.0	2.1	1.2	1.4	2.4	2.4
Zakarpattia	5.1	5.7	6.1	6.6	2.0	2.5	6.1	7.2
Zaporizhzhia	2.8	0.7	1.6	0.4	5.7	1.7	3.4	0.8
Ivano-Frankivsk	2.8	3.0	3.1	3.3	1.9	2.3	2.3	2.5
Kyiv	3.8	4.1	4.0	4.1	3.4	3.9	3.5	4.3
Kirovohrad	1.0	1.2	0.4	0.6	1.9	2.3	3.9	4.7
Luhansk	2.7	2.1	1.7	1.3	5.9	4.6	0.6	0.4
Lviv	5.9	7.4	6.4	8.1	4.7	6.0	4.9	5.2
Mykolaiv	1.3	0.9	0.8	0.6	2.3	1.6	2.9	2.1
Odesa	4.4	4.8	2.2	2.2	9.9	11.8	7.6	7.5
Poltava	5.5	6.2	4.5	4.8	8.3	10.2	6.3	6.8
Rivne	4.1	4.4	2.8	2.8	7.4	8.8	5.0	5.4
Sumy	0.7	0.6	0.7	0.6	0.8	0.9	0.1	0.1
Ternopil	4.6	5.5	5.7	6.8	2.0	2.3	2.0	2.0
Kharkiv	2.1	1.4	1.8	1.1	3.1	2.6	0.9	0.7
Kherson	1.7	-	1.2	-	3.2	-	0.5	-
Khmelnytskyi	10.2	11.1	11.2	11.7	7.9	9.5	8.3	9.3
Cherkasy	1.5	1.6	0.9	0.9	1.5	1.4	8.8	11.6
Chernivtsi	12.4	14.0	15.0	16.5	6.2	7.6	8.3	8.4
Chernihiv	0.7	0.8	0.7	0.7	1.0	1.1	0.3	0.4
Production in Ukraine, thous. t	**2,096**	**1,875**	**1,449**	**1,323**	**5,317**	**4,454**	**1,155**	**1,069**

Notes: * – data without considering the territories temporarily occupied by the Russian Federation and parts of the territories where military operations are (were) being conducted
Source: calculated by the authors based on State Statistics Service of Ukraine (n.d.)

For all types of fruits, there is a decrease in production volumes during the war: pome fruits – by 9%, stone fruits – by 16%, nuts – by 7%. However, it should be borne in mind that some of the data was not statistically considered for the territories where the fighting continues. It is also worth noting that the main share of fruit production of pome fruits – up to 70% before and during the war (on average up to 1 mln. t) is concentrated in Vinnytsia, Dnipro, Zakarpattia, Lviv, Ternopil, Khmelnytskyi, and Chernivtsi oblasts. The leaders among them are Vinnytsia and Chernivtsi oblasts. Thus, it is in the Vinnytsia Oblast that the main production of apples in Ukraine is concentrated – up to 20%, and in Chernivtsi oblast, pears – 16%. During the war, the production of pome fruits significantly decreased in Zaporizhzhia, Donetsk, Kharkiv, Mykolaiv, Luhansk, and Dnipro oblasts by 80.74%, 43%, 39%, 28%, and 24%, respectively. Moreover, production in the Kirovohrad Oblast increased significantly – by 24%, which is explained by the entry of young apple orchards into commercial fruiting.

Regional stone fruit production experienced the greatest structural shift during the war. Thus, before the war in 2021, the main share of gross collections (an average of 61%) was concentrated mainly in the Dnipro, Donetsk, Zaporizhzhia, Odesa, Poltava, Rivne, Khmelnitsky, Chernivtsi oblasts, which is 321 thous. t. During the war, stone fruit production in Zaporizhzhia, Donetsk, Mykolaiv, Luhansk, Kharkiv, and Cherkasy oblasts decreased by 74%, 68%, 43%, 34%, 30%, and 21%, respectively. However, production in the Vinnytsia Oblast increased by 20%.

Nut cultivation was concentrated in 2021 mainly in Dnipro, Donetsk, Zakarpattia, Odesa, Poltava, Khmelnytskyi, Cherkasy, and Chernivtsi oblasts – up to 65%. During the war, production decreased the most in the Donetsk and Zaporizhzhia oblasts – by 69% and 78%. Plantings entered commercial fruiting in the Vinnytsia Oblast, due to which the gross harvest of nuts, on the contrary, increased by 79% to 7.7 thous. t. More than 82% of fruit-bearing walnut plantations (13.3 thous. ha) are concentrated in households, which is more than 95% of total production. Because of this, the study suggests that after the war, the production of nuts (mainly walnuts – 99.9%) will recover with a minimum level of financial investment.

Summing up, the main share of gross fruit collections for all categories of farms is concentrated in the Vinnytsia Oblast – an average of 13% (2.5-2.6 mln. t). Most of

all, their production decreased during the war in Zaporizhzhia, Donetsk, Mykolaiv, Kharkiv, and Dnipro oblasts – by 77%, 71%, 40%, 38%, and 21%, respectively. There are no data on the state of plantings in the Kherson Oblast. Given the existing reduction and structural changes in regional production of various types of fruits due to the war in Ukraine, the deterioration of the situation not only with sufficient consumption, but also availability, it is especially important to establish effective and timely interregional logistics, given the concentration of the main share of gross fruit collections in households.

When drawing up a balance sheet of fruits, their wide interspecies range and channels of supply should be considered. Thus, first of all, this affects the calculation of such items as feed, seeds, processing for non-food needs and product losses. For example, if the permissible fruit losses in agricultural enterprises are up to 5%, then in households this figure is several times higher. During 2019-2023, there was a dynamic decrease in the fruit consumption fund – from 2,382 thous. t in 2019 to 2,001 thous. t in 2023, that is, by 15.6% (Table 3). However, mainly due to a 20.8% reduction in the population during this period to 33.2 million people, the level of consumption increased by 6.2% to 60.3 kg per person per year. The established consumer demand corresponds to a rational consumption rate of 75 kg per person per year by 80.4%.

Table 3. Fruit balance in Ukraine, thous. t

Indicators	Years					Index 2023 to 2019
	2019	2020	2021	2022	2023	
General offer	4,008	3,746	3,944	3,602	3,532	0.9
Inventory at the beginning of the year	1,236	1,110	972	1,170	1,045	0.8
Production	1,989	1,741	2,096	1,871	1,875	0.9
Import	782	896	875	560	612	0.8
Total demand	2,898	2,775	2,773	2,557	2,485	0.9
Domestic demand	2,715	2,647	2,618	2,388	2,315	0.9
food	2,382	2,356	2,267	2,074	2,001	0.8
feed	41	38	41	38	37	0.9
seeds	3	3	3	3	3	1.0
processing for non-food needs	239	209	252	225	225	0.9
losses	50	42	55	48	49	1.0
Export	183	128	155	169	169	0.9
Balance at the end of the year	1,110	972	1,170	1,045	1,047	0.9
Comparison of final balances with demand	0.38	0.35	0.42	0.41	0.42	-
Consumption fund	2,382	2,356	2,267	2,074	2,001	0.8
Market capacity	1,453	1,437	1,383	1,244	1,201	0.8
Consumption per person per year, kg	56.8	56.6	55.1	59.3	60.3	1.1

Source: calculated by the authors based on State Statistics Service of Ukraine (n.d.)

The fruit market capacity calculated in dynamics for 2019-2023 is 1,201-1,453 thous. t. This is exactly the volume of fruit supply that goes through all stages of commodity-money market relations. This indicator shows that the consumer demand of the population is met only up to 40%. That is, there is a high level of self-sufficiency of the population at the expense of their own natural production. As a result, this leads to differentiation in fruit consumption – interregional (between urban and rural populations), interspecific (between pomological varieties), etc. Thus, the rural population, in contrast to the urban population, consumes less fruits of objectively necessary imports, in particular, citrus fruits and bananas.

In the development of the fruit market capacity by all categories of farms, i.e., agricultural enterprises and households in different years, mainly depending on the volume of their production, a share is allocated in the range of 35-45%. The volume of imports as part of the capacity is up to 65%. The total demand for fruits was set considering the volume of products for fresh consumption, direction for processing, and export supplies. In 2030, the total demand may reach 2,635 thous. t (Table 4). It is planned to expand the fruit consumption fund to 2,288 thous. t by 2030 by increasing their production volumes to 2,100 thous. t, including pome fruits – 1,480 thous. t, stone fruits – 500 thous. t, and nuts – 120 thous. t.

Table 4. Total demand for fruits and sources of coverage in 2030

Products	Rational consumption rate, kg/ person/year	Total demand, thous. t				Sources of coverage of needs, thous. t			Consumption fund, thous. t	Share of coverage of internal needs, %
		total	of them		incl. for recycling	agricultural enterprises	households	import		
			population	export						
Fruits, including:	75	2,635	2,400	235	130	420	1,680	125	2,288	86.8
▸ pome fruits	57.5	2,012	1,840	172	100	400	1,080	25	1,638	81.4

Table 4, Continued

Products	Rational consumption rate, kg/ person/year	Total demand, thous. t				Sources of coverage of needs, thous. t			Consumption fund, thous. t	Share of coverage of internal needs, %
		total	of them		incl. for recycling	agricultural enterprises	households	import		
			population	export						
▸ stone fruits	16	560	512	48	28	15	485	80	620	110.7
▸ nuts	1.5	63	48	15	2	5	115	20	30	47.6
Citrus fruits and bananas	3	96	96	-	6	-	-	800	784	816.2

Source: calculated based on the authors' research

Consequently, the share of covering domestic needs in 2030 may reach 86.8%, including at the expense of Ukrainian production by 91.8%. This volume of the fruit consumption fund can meet the consumer demand of the population, with its projected number of 32 million people for 2030, by 95.3%, which is 71.5 kg per person per year, including pome fruits by 89.0% (51.2 kg), stone fruits – 121.1% (19.4 kg) and nuts – 62.5% (0.9 kg), objectively necessary import supplies – 816.7% (24.5 kg) (Kurylo *et al.*, 2023). In the near future, the main role in Ukrainian production of all types of fruits will traditionally belong to households.

The use of intensive technologies in the creation and maintenance of gardens of various structures is important in increasing the competitiveness of horticultural products on the Ukrainian and global markets. This allows increasing the productivity of plantings almost three times, for example, apple and pear trees – up to 35-45 t/ha, cherries and black cherries – 15-20, plums – 30-40 t/ha, etc. In general, dense gardens on low-growing clone rootstocks are considered promising. The improvement of the breed and varietal composition of fruit plantations is seen in increasing the share of winter varieties of pome and early stone fruits, in particular, sweet cherries, along with improving the storage and transportation of fruits, the use of commercial processing. This will allow expanding the export of fresh fruits in the future. In the presence of a specially equipped storage facility, horticultural enterprises can receive almost twice as high profits as when selling fruits during their mass fruiting period.

During the study period for 2019-2023, state financial support was provided in the field of gardening, the amount of which amounted to UAH 400-450 million annually. The funds were used by production workers for the purchase of seedlings, the construction of trellises, and the installation of drip irrigation systems, for the construction or renewal of refrigeration facilities, storage facilities, the purchase of equipment for commodity refinement, complete set of fruit and vegetable products, and necessary equipment or other installations important in the production process, including from foreign companies. In 2023, according to the Resolution of the Cabinet of Ministers of Ukraine No. 738 (2022), UAH 432.8 million was allocated for grants for the development of horticulture, berry growing, and viticulture. Horticulture will continue to require additional state financial support, especially during the war, due to the critical reduction in the area of fruit-bearing plantings and the need to recreate gardens at least at the level of old plantings that have left commercial fruiting.

In ensuring the needs of the population with fruit products, a significant place was occupied not only by the sufficiency indicator, but also by access to fruit consumption by their range and variety. This is especially true for people with low levels of financial security. Therefore, it is quite important to develop an effective sales system depending on the territorial location and population density. One of the best sales options is mobile grocery markets. The relationship between the level of consumption and the existing functioning of such markets was investigated by B.-S. Hsiao *et al.* (2019). Moreover, researchers were exploring the relationship between meeting the needs of the population with fruit and its access to produce and obesity. Such studies were conducted on a sample of more than 3,000 people in five countries of the world by S. Yang *et al.* (2021). Based on correlation and regression analysis, a significant level of dependence was established in favour of the need for fruit consumption in accordance with established rational norms.

In Ukraine, as in many countries of the world, there is a differentiation in fruit consumption depending on seasonality and, with low purchasing power, price fluctuations. Analytical studies aimed at the rationality of ensuring consumer demand, investigating the price situation, sales channels, marketing and pricing policies of enterprises, were conducted by K. Chay *et al.* (2019) and F. Bachewe & B. Minten (2023). The need for marketing research in the activities of farms, determining the benefits of selling fruit through different sales channels was noted by H. Ihli *et al.* (2022). Special attention should be paid to research on fruit sales due to their rapid loss of consumer properties, seasonality, overall size, the need to comply with storage technologies and the availability of necessary storage facilities. Studies of various factors and their impact on the efficiency of marketing fruits, in particular mangoes and peaches, through various channels were carried out by D. Endias (2021) and D. Natalchuk & O. Rudnyk-Ivashchenko (2024). The authors of the current study suggest that the optimal sales channel for fruit producers in this case is a network of wholesale fruit and vegetable markets. The need for the organisation of functional fruit market centres was noted by S. Rashid *et al.* (2023) and R. Kuralbayeva *et al.* (2023). This can partially solve the problem of access and provision of fruits to various categories of the population.

It should be noted that in the balance sheet compiled in the study, fruit waste is reflected in three items: livestock feed costs, processing for non-food needs, and product

losses. Losses of production, especially in harvest years, mainly apples, are quite noticeable in households, which, in fact, is not statistically recorded. The issue of using fruit waste by anaerobic digestion for the production of biogas was studied by C. Morales-Polo *et al.* (2019). There is an acute issue of fruit loss in the process of the entire consumer chain "production-trade-consumer" among German market operators, especially in too productive years, which was investigated by R. Herzberg *et al.* (2022). The study of the behaviour of fruit sellers at a high level of product waste, including in wholesale fruit and vegetable markets, was carried out by B. Abadi *et al.* (2021). The researchers also investigated the behaviour of direct consumers in handling fruit waste. These cross-sectional studies were ultimately aimed at improving the quality of management and increasing the sales impact. These studies, together with the current research, once again confirmed the urgent need to develop the fruit processing industry in Ukraine.

Analytical studies of fruit production by various categories of farms were carried out by R.S. Sengar & R. Varsha (2020). Especially relevant is the issue of selling fruits by small commodity producers – households of the population and determining their place in providing the population in the future. The issue of using products for their own consumption in fresh form or processing was not discussed. The problem of selling crop surpluses is acute when quality requirements and compliance with standards are tightened, due to the fact that these producers occupy a significant share in gross fees. Similar studies on the place of small producers in Bosnia and Herzegovina in the food system and the problem of their inclusion in the modern market chain have been carried out by I. Plazibat *et al.* (2016). According to the authors of the above study, the real guide for households to occupy their market niche is the creation of consumer cooperatives, which would solve the issue of forming standard batches of fruit products. This is quite relevant for walnuts, which for a long time occupied the main share in Ukrainian export supplies and are in quite high demand outside of Ukraine (fresh, as raw materials for processing).

The need for state financing of horticulture to expand industrial production and, accordingly, guaranteed (controlled) provision of internal and external needs for fresh and processed fruits is debatable. The need for state regulation, including financial support for the agricultural market, despite the status of "Ukraine as an EU candidate", and thus intensification of cooperation with the European Union, which ultimately leads to a reduction in state protectionism in various areas, is supported by M. Kuryljik & I. Kochan (2024). The researchers, however, suggest that state financial support for horticultural producers is necessary, especially for laying stone fruit plantations.

Gardening is also actively supported in other countries of the world. But given the deterioration of the environment, climate change, and population growth, the problem of providing horticultural products to residents of India is significant. Although India has favourable conditions for growing almost all types of fruit, government intervention and support are necessary for the sustainable development of horticulture, as stated by P. Bakshi *et al.* (2022). In the United States, the development of horticulture is supported by the state and private investors, and scientific research in this area. Efforts are made to overcome misunderstandings and misunderstandings between direct consumers of horticultural products that generate demand and industrial producers to ensure optimal food supply, which has been studied by S. Krishnan *et al.* (2021).

Thus, the most relevant and discussed issues in the development of the fruit market and horticulture in particular, which were investigated by researchers are: development of a high-quality commodity supply of fruits, optimal provision of consumer demand and the needs of the population; the need for marketing research and improvement of the sales policy of horticultural enterprises; the development of the processing industry, rational environmental use of waste. The opinions of researchers are generally well-founded and non-conflicting. However, the issue of the need for financial support for agriculture in various areas, including horticulture, remains debatable. Ultimately, despite the integration of Ukraine into the European space, in 2025, the state remained the main source of investment in the development of Ukrainian industrial horticulture.

▸ Conclusions

The reduction of the area of fruit-bearing plantings in horticultural enterprises and the concentration of the main share of fruit production in households causes an unorganised development of their product supply. There is a reduction and structural changes in regional production of various types of fruits due to the war in Ukraine. This necessitates the optimisation of logistics between operators of the entire food chain – producers, intermediaries, merchants, and consumers. The volume of the fruit market capacity provides consumer demand of the population only up to 40%. That is, most fruit products reach the consumer outside of commodity-money relations.

The total needs for fruits for 2030 are set, which, given the current economic situation in Ukraine and the corresponding state financial support, can be met by 86.8%. Traditionally, the main share in the development of the fruit consumption fund will be occupied by households. It should be noted that these products are uncompetitive and can be used primarily for domestic consumption and processing. The exception is walnuts (peeled and unpeeled), which are purchased by intermediaries from the population and exported mainly as raw materials for the processing industry. Import supplies of fruits will be formed mainly at the expense of citrus fruits and bananas, and export – apples grown by horticultural enterprises. But it is expected that the production of the latter will resume at least to the pre-war level.

In the future, for the expansion of industrial fruit production, it is necessary to regularly provide financial support to horticultural enterprises for the reproduction and care of fruit plantations, storage of crops in specially equipped storage facilities. It is important that gardening develops on an intensive basis, using modern innovative environmentally safe technologies for growing perennial plantings. In further studies, it is necessary to establish the volume of financial investment for laying and caring

for perennial plantings (including by attracting foreign sources), in accordance with their placement in the regional context in the near future, considering the military operations in Ukraine and the presence of uncontrolled territories. After all, the primary task is to provide the population with fresh and processed products, reduce import dependence, and expand the export potential of Ukrainian horticulture.

▸ Acknowledgements
None.

▸ Funding
None.

▸ Conflict of interest
None.

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▸ **Анотація.** Під час війни існує необхідність забезпечення усіх учасників ринку плодовою продукцією переважно українського виробництва та зменшення імпортозалежності. Для цього важливо встановити показники фактичного рівня споживання та загальні і внутрішні потреби у перспективі, а також можливості їх забезпечення. Мета статті – встановити та здійснити оцінку фактичного фонду споживання плодів в Україні, враховуючи продовольчий дисбаланс під час війни, та перспективні показники споживання, потреби і можливі джерела їх покриття. В основі детального аналізу ринкового середовища, його змін та взаємовпливу, використано балансовий метод, який забезпечує комплексне вивчення кон'юнктури і дозволяє змоделювати економічну ситуацію на перспективу. При встановленні перспективних параметрів українського ринку застосовувалися прийоми кореляційно-регресійного аналізу. Встановлено, що в Україні формування товарної пропозиції плодів здійснюється неорганізовано, зважаючи на зосередження основного їх виробництва в господарствах населення – на 80 %. Це обумовлює диференціацію у забезпеченні споживчого попиту населення у розрізі регіонів країни, за асортиментом та сортиментом, за місцем проживання. Основна частка виробництва плодів (переважно зерняткових – 90 %) концентрується у Вінницькій області (13 %). Через війну, найбільш знизився валовий збір у Запорізькій, Донецькій, Миколаївській, Харківській та Дніпропетровській областях, що обумовлює необхідність оптимізації міжрегіональної логістики. Фонд споживання характеризується динамічним зменшенням, що обумовило забезпечення попиту населення у свіжих та переробних плодах на 80,4 %. Місткість ринку покриває попит лише на 40 %, що свідчить про високий рівень натурального виробництва та самозабезпеченості населення. У перспективі на 2030 р. очікується незначне збільшення українського виробництва, поставок об'єктивно-необхідного імпорту (цитрусові, банани), забезпечення внутрішніх потреб населення на 86,8 %. У подальшому, зважаючи на необхідність розширення промислового інтенсивного садівництва на інноваційній основі, для оптимального забезпечення загальних потреб у плодах, необхідною є державна фінансова підтримка цього виду діяльності. Результати досліджень слід використати при формуванні перспективної програми продовольчого забезпечення на короткостроковий період у контексті оптимального забезпечення населення та всіх операторів ринку свіжою та переробною плодовою продукцією

▸ **Ключові слова:** виробництво; пропозиція; попит; фонд споживання; місткість ринку; загальні потреби

Received: 03.07.2024. Revised: 17.12.2024. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.50

Ekonomika APK, 32(2), 50-62

UDC 338.43:633.1

Assessment of structural changes in exports and price situation on the Ukrainian grain market during the war

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► **Abstract.** The study aimed to assess the main export problems, measure price imbalances in the grain market, and compare the impact of world prices and exchange rate dynamics on domestic selling prices of wheat and corn before and during the war. The following methods were used: comparative analysis, statistical, tabular, graphical, calculation and design, abstract and logical, as well as correlation and regression analysis tools. The study revealed a significant structural transformation of wheat and corn exports during the war, with an almost twofold decrease in the share of Asian countries and an increase in the share of European countries in wheat exports from 1.7% to 48.3% and corn from 32.7% to 56.8%. The negative impact of the logistics transformation of exports on domestic and foreign prices in the grain market was determined. Compared to the pre-war period, domestic wheat and corn prices decreased by 22.7% and 28.2%. An indicative definition of price disproportions showed that before the war, world prices for wheat and corn almost corresponded to domestic prices, while during the war this ratio increased to 2.2 and 1.6 times, respectively. The modelling shows that before the war, a 1 USD/t increase in the global wheat price led to an equivalent increase in the domestic selling price by 0.71 USD/t, while a 1 UAH increase in the dollar increased the price by 3.2 USD/t. The impact of the selected factors has changed dramatically in the war: a corresponding increase in the global wheat price

► **Suggested Citation**: Cheremisina, S., Rossokha, V., Selinnyi, M., Balan, O., & Nahornyi, V. (2025). Assessment of structural changes in exports and price situation on the Ukrainian grain market during the war *Ekonomika APK*, 32(2), 50-62. doi: 10.32317/ekon.apk/2.2025.50.

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by 1 USD/t leads to an increase in the domestic selling price by only 0.19 USD/t, which is almost 4 times less than in peacetime, and a 1 UAH increase in the dollar reduces the domestic selling price of 1 tonne of wheat by 2.26 USD/t. The corresponding impact of the global corn price increase on the domestic price during the war was halved from 0.66 to 0.31 USD/t, and the upward movement of the exchange rate by 1 UAH reduced the selling price of corn by 4.65 USD/t

▸ **Keywords:** world price; exchange rate; price distortions; price elasticity; impact modelling

▸ Introduction

Despite the war, Ukraine remains a major agricultural producer. Ukrainian producers not only provide a significant share of Ukrainian budget revenues but also create the foundation for Ukraine's food security. The grain market is an important component of the agricultural sector of the economy. In 2021, the share of grain in Ukraine's total exports was 18.1%. During the full-scale war, these relative figures increased significantly. Thus, in 2022, the export share of grain crops increased to 20.6%, and in 2023 to 23%. In the first half of 2024, the export revenue from grain sales exceeded USD 5.3 billion. Its share in total exports was 26.9% (State Statistics Service of Ukraine, n.d.). Despite the war, losses, complicated logistics, and the destruction of infrastructure, as of 2025, farmers continue to work, trying to overcome difficulties and challenges. It is necessary to conduct a comprehensive monitoring of structural changes in the export sector of the Ukrainian grain market during the war, identify price imbalances in the grain market, and model the impact of world prices and exchange rate dynamics on domestic sales prices of wheat and corn, the main export crops.

The issues of organisational, economic and logistical challenges faced by Ukrainian grain exports since the beginning of the full-scale war, the definition of price fluctuations and the assessment of the growing disparity in the relations between grain market participants have been the subject of research by many authors. O. Lotysh (2022) assessed the role of Ukraine in the world grain market and analytically monitored the challenges and threats that had a destructive impact on the country's grain sector. The author assessed the existing potential of the grain market, outlined the fundamental risks caused by the war and focused on the negative impact of price imbalances on the global food market. Analytical monitoring of the priority problems of the grain market in Ukraine in the context of the war was addressed by I. Savenko *et al.* (2022). The authors identified the current state and key factors of supply formation in the grain market, outlined several practical measures to stabilise it, and proposed an effective methodological and practical toolkit for studying the problems of the grain market in wartime.

R. Miroshnyk & I. Bahlai (2022) analysed the main problems of the Ukrainian grain market, highlighting the negative trends in the deterioration of priority market indicators during the war. The authors emphasise the important role of maintaining and adapting the logistics system of grain market producers to the conditions of martial law. As a primary task for the functioning of grain market participants, the authors emphasise the need to ensure the break-even level of their production. According to the authors, active state policy and support from international partners will minimise the impact of negative factors caused by the war on the grain market.

T. Ostashko (2024) studied several relevant issues that arose in the export sector of the grain market with the outbreak of a full-scale war. The author identified the risks and the real scale of the impact of the loss of grain export markets on the Ukrainian economy and assessed the impact of the war on the global grain market and food security in the world. The study focuses on the disparity in the relationship between rural producers and grain traders, the main consequences of which are a significant reduction in grain purchase and export prices. Particularly noteworthy are the results of a study of the impact of the war on grain export prices, followed by a determination of the losses of each participant in the price chain.

M. Zhybak & H. Khrystenko (2024), addressing the crucial role of the grain market in ensuring food security at the national and global levels, outlined several problems of the Ukrainian grain market in wartime. The authors monitored seasonal price fluctuations in the grain market and established the dependence of domestic sales prices of wheat and corn by Ukrainian agricultural enterprises on the dynamics of world prices. O. Bezsmertna & Ye. Musyca (2024) analysed the transformational changes that objectively occurred in grain exports during the war. The authors conducted a thorough analysis of export flows in the grain market, analysed the existing geographical changes in exports, outlined current structural trends and identified the priority consequences of the impact of a full-scale war on the global food crisis.

H. Khrystenko & L. Yarema (2024) conducted a comparative analysis of structural and indicative indicators of grain exports in the pre-war period and during the war. The authors analysed the dramatic changes that have occurred in the foreign trade of the Ukrainian grain market: increased risks, geographical reorientation of export flows, and complicated logistics. A comparative analysis of the geographical structure of grain exports formulated the top 10 countries that imported grain from Ukraine during the war.

E. Prushkivska & R. Kovalenko (2023) analysed the peculiarities of the functioning and structuring of the world grain market in the context of geopolitical instability. The authors conducted a comparative characterisation of the current market trends in the global and national grain markets during the war. The authors emphasise that grain production is a fundamental component of the global economy, and the leading grain-exporting countries can turn their existing agricultural potential into effective levers of their economic policy and strengthen their geopolitical position.

A. Nechyporuk *et al.* (2022) assessed the destructive transformations of grain export logistics caused by the war. The authors identified and compared the capacity of alternative sea routes for grain exports and assessed the urgent

problems of grain supply chain management. Among the main directions of establishing grain logistics and increasing the capacity of the railway infrastructure, the authors highlight the construction of "dry ports", and organisational and structural reorientation of logistics to the western borders of Ukraine based on foreign project investment.

I. Protsyk & A. Beze (2022) conducted a thorough analysis of global trends in the development of the market components of wheat and corn (production, yields, exports, prices) and indicatively defined the place and role of Ukraine. The authors analysed the retrospective dynamics and variability of prices for grain futures formed on leading international commodity exchanges. The authors identified the main factors that influenced the global price policy for grain crops before the outbreak of a full-scale war with Russia and after 24 February 2022. O. Shandrivska & O. Pyzh (2024) identified the negative impact of the war on the production scale and structure of grain exports using a system of indicators. The authors assessed the transformation of the export potential of Ukraine's grain market during the war and focused on the factor impact on price dynamics and price volatility. The authors proposed a set of effective measures to stabilise and further develop the production and export potential of the grain market in Ukraine.

N. Gafarov *et al.* (2022) conducted a comparative analysis of the availability and patterns of transformation of the production and export potential of grain crops in Ukraine during the war. The authors developed and practically interpreted variational models of grain export flows, incorporating possible scenarios of Ukrainian economic development. Based on regression analysis, the authors determined the impact of the main factors on the export potential of the grain market, namely production volumes, purchase prices, availability and sufficiency of the mineral and organic fertiliser system. To minimise the negative impact of these factors on the decline in the export potential of the grain market, the authors proposed to increase the pace of technological development of grain production, storage and transport logistics.

These studies analysed the negative impact of a full-scale war on grain exports from Ukraine, destructive changes in grain export logistics, and analytical assessment of fluctuations in domestic and world grain prices but lack elements of calculated and constructive determination of price imbalances in the grain market and modelling the impact of world prices and exchange rate dynamics on domestic grain prices. The study aimed to comprehensively assess the priority problems of exports and price distortions that occurred on the grain market and to model the impact of world prices and exchange rate dynamics on domestic selling prices of wheat and corn before and during the war. The achievement of the remaining goal required the consistent solution of the following tasks: to assess transformational changes in the structure of grain exports during the war; to conduct comparative monitoring of price imbalances in the grain market before and during the war; to develop a correlation and regression model of the impact of world prices and the exchange rate on the dynamics of domestic sales prices of wheat and corn by farmers before and during the war with the analytical definition of relevant indicators.

▸ Materials and methods

A range of research methods were used. The method of comparative analysis was used for analytical monitoring of the dynamics of grain exports in Ukraine and indicators of average selling prices of grain crops by agricultural enterprises. The calculation and constructive method were used to determine the transformational changes that occurred in the structure of wheat and corn exports during the war. The statistical method was used to determine the retrospective dynamics of price ratios in the markets of the main export-oriented crops – wheat and corn before and during the war.

The method of correlation and regression analysis alongside the definition and analytical interpretation of the system of coefficients (multiple correlations, determination, Fisher's criterion, Student's t-test) were used to determine the impact of world prices and the exchange rate on the dynamics of domestic sales prices of wheat and corn by domestic farmers before and during the war. Using the tabular method, the study illustrates the identified comparative and effective parameters of the practical application of the correlation and regression modelling tools. The graphical method is used to illustrate the results of modelling the dependence of domestic sales prices of wheat and corn by agricultural enterprises on the dynamics of world prices and exchange rate fluctuations. The abstract and logical method is used to formulate conclusions.

The conceptual feature of the study is a comprehensive assessment of structural transformations of grain exports from Ukraine, analytical monitoring of price imbalances in the grain market and modelling the impact of world prices and exchange rate dynamics on domestic sales prices of wheat and corn. The following logistic coefficients of the price ratio were used as calculation and statistical tools for analysing the retrospective dynamics of price imbalances in the grain market:

$$K_{1i} = \frac{Wp_{w(c)i}}{Sp_{w(c)i}}, \quad (1)$$

where K_{1i} – logistic coefficient of the correlation with the world price in the i-th period; $Wp_{w(c)i}$ – average annual world price of wheat and corn in the i-th period, USD/t; $Sp_{w(c)i}$ – average annual cost of sale on domestic wheat and corn market in the i-th period, USD/t.

$$K_{2i} = \frac{Ep_{w(c)i}}{Sp_{w(c)i}}, \quad (2)$$

where K_{2i} – logistical coefficient of the correlation with the export price in the i-th period; $Ep_{w(c)i}$ – average annual export price of wheat and corn in the i-th period, USD/t.

Price, as an economic phenomenon, can be objectively determined by a certain set of factors that can both simultaneously and retrospectively change the vectors of their influence. Notably, it is impossible to study all the causal relationships of influence. During the study, the retrospective dynamics of domestic sales prices of wheat and corn by agricultural enterprises was chosen as a random variable *Y*. The retrospective sequence of their statistical values is structured into two periods:

- $y_1, y_2, y_3, y_4, \ldots\ldots\ldots y_n$, where n – number of observations in the sample – 158 (from 1.01.2009 to 1.03.2022);

▸ $y_1, y_2, y_3, y_4, \ldots\ldots\ldots y_n$, where n – number of observations in – 28 (from 1.03.2022 to 1.07.2024).

As independent factors of influence, the retrospective of world prices for wheat and corn (X_1) and the dynamics of the exchange rate of the national currency of Ukraine against the US dollar (X_2) were selected with the appropriate structuring for two periods. The functional dependence of domestic sales prices of wheat and corn by agricultural enterprises on the selected independent factors of influence can be described as follows:

$$Y = F(X_1, X_2). \quad (3)$$

Identification of the objective presence and influence of uncertain random factors that are of a force majeure nature and cannot be measured by specific indicators, notably, the selected random variable Y (internal sales price) will fluctuate from the functional dependence. In this case, the dependence of domestic selling prices for wheat and corn on their global indicators and exchange rate dynamics will be stochastic rather than functional and will have the following mathematical interpretation:

$$Y = F(X_1, X_2) + \varepsilon, \quad (4)$$

where ε – random deviation.

Further practical implementation of the methodological tools of correlation and regression modelling of the dependence of domestic sales prices of wheat and corn by agricultural enterprises on the dynamics of world prices and exchange rate fluctuations is based on the assumption of a linear relationship between Y and X_1, X_2:

$$y_{wi} = a_0 + a_1 x_{wi} + a_2 x_{eri} + \varepsilon_i; \quad (5)$$

$$y_{ci} = b_0 + b_1 x_{ci} + b_2 x_{eri} + \varepsilon_i, \quad (6)$$

where a_0, a_1, a_2, b_0, b_1, b_2 – parameters of regression equations; y_{wi} – monthly dynamics of wheat sales price by agricultural enterprises in the i-th period, USD/t; y_{ci} – monthly dynamics of corn sales price by agricultural enterprises in the i-th period, USD/t; x_{wi} – monthly dynamics of world wheat prices in the i-th period, USD/t; x_{ci} – monthly dynamics of world corn prices in the i-th period, USD/t; x_{eri} – monthly dynamics of the USD/UAH exchange in i-th period, UAH per 1 USD; ε_i – random deviation, which interprets the cumulative impact of unaccounted factors and randomness.

The algorithm for determining the relationship between the selected parameters of the correlation and regression model included the following list of logically interrelated tasks: determining and estimating the parameters (coefficients) of the regression equations (a_0, a_1, a_2, b_0, b_1, b_2) based on a retrospective of the statistical arrays of the relevant indicators; measuring quantitative parametric signs of the relationship between Y independent factors X_1 and X_2; assessment of the statistical significance of the coefficients of the regression equation; analytical measurement of the degree of influence of the independent variable factors on the parametric value of Y; determination and measurement of the elasticity (sensitivity) of the resultant attribute Y from fluctuations in the factor attributes X_1 and X_2 by 1%.

The list of the above tasks was solved by using the MS Excel software package in practice. The sensitivity of the selling price of wheat and corn to changes in the world price of the respective crops and the exchange rate by 1% was measured using the following formulas:

$$E_{x1} = f'(x_1)\frac{\bar{x}_1}{\bar{y}}; \quad (7)$$

$$E_{x2} = f'(x_2)\frac{\bar{x}_2}{\bar{y}}. \quad (8)$$

Assuming a linear relationship between Y and X_1, X_2, the corresponding formulas are as follows:

$$E_{wx1} = a_1\frac{\bar{x}_{wi}}{\bar{y}_{wi}}; \quad (9)$$

$$E_{wx2} = a_2\frac{\bar{x}_{eri}}{\bar{y}_{wi}}, \quad (10)$$

where E_{wx1} – coefficient of elasticity (sensitivity) of the wheat sales price by agricultural enterprises depending on the change in the world wheat price by 1%; E_{wx2} – coefficient of elasticity (sensitivity) of wheat sales price by agricultural enterprises depending on exchange rate fluctuations by 1%; a_1, a_2 – corresponding coefficients of the equations obtained in the course of correlation and regression modelling.

$$E_{cx1} = b_1\frac{\bar{x}_{ci}}{\bar{y}_{ci}}; \quad (11)$$

$$E_{cx2} = b_2\frac{\bar{x}_{eri}}{\bar{y}_{ci}}, \quad (12)$$

where E_{cx1} – coefficient of elasticity (sensitivity) of the selling price of corn by agricultural enterprises depending on the change in the world price of corn by 1%; E_{cx2} – coefficient of elasticity (sensitivity) of the selling price of corn by agricultural enterprises depending on exchange rate fluctuations by 1%; b_1, b_2 – corresponding coefficients of the equations obtained in the course of correlation and regression modelling.

The empirical basis of the study is based on Official website of the State Statistics Service of Ukraine (n.d.), statistical data of Index Mundi Open Data Portal (n.d.), informational materials of the Minfin (n.d.) and Ministry of Agrarian Policy and Food of Ukraine (n.d.).

▸ Results and discussion

For a long time, Ukraine has been earning almost 10 billion USD annually from grain exports. Despite the war, these figures for the period 2022-2024 remain almost unchanged. For instance, in the first military year of 2022, export earnings from grain sales totalled 9.1 billion USD, including 2.7 billion USD of wheat, 5.9 billion USD of corn, and 0.45 billion USD of barley. In 2023, the export revenue of grain traders decreased by 8.8% to 8.3 billion USD. In the first half of 2024, grain exports have already reached 5.2 billion USD, including 10.8 million tonnes of wheat exported for 1.8 billion USD, 19.8 million tonnes of corn (3.2 billion USD), and 1.4 million tonnes of barley (0.2 billion USD). However, the volume of grain exports declined during the war, especially in 2022. Thus, compared to 2019, grain exports in the first year of the war decreased by 32.1% or 18.2 million tonnes, including wheat almost halved (from 20 to 11.2 million tonnes), corn by 22.9% (from 32.3 to 24.9 million tonnes), and barley by

48.8% (from 4.1 to 2.1 million tonnes). In 2023, natural export volumes increased relatively to 44.8 million tonnes: 16.2 million tonnes of wheat, 26.4 million tonnes of corn, and 2.2 million tonnes of barley (Table 1).

Table 1. Dynamics of grain exports in Ukraine in 2019-2024

Types of crops	2019		2020		2021		2022		2023		2024, the first half of the year	
	million tonnes	million USD	million tonnes	million USD	million tonnes	million USD	million tonnes	million USD	million tonnes	million USD	million tonnes	million USD
Total	56.7	9,633.3	51.3	9,410.7	50.8	12,343.8	38.5	9,108.2	44.8	8,306.7	32.1	5,263.4
Wheat	20.0	3,658.4	18.1	3,595.5	20.1	5,074.8	11.2	2,675.6	16.2	2,941.0	10.8	1,838.7
Barley	4.1	710.1	5.0	877.5	5.7	1,275.4	2.1	446.4	2.2	362.4	1.4	219.7
Corn	32.3	5,218.3	27.9	4,877.1	24.7	5,892.7	24.9	5,934.2	26.4	4,966.4	19.8	3,179.3
Rice	0.006	4.470	0.005	4.011	0.010	6.331	0.001	0.974	0.000	0.140	0.003	4.114
Buckwheat	0.001	0.474	0.000	0.268	0.001	0.760	0.000	0.266	0.001	0.369	0.001	0.483
Other	0.2	41.7	0.3	56.4	0.4	94.0	0.2	50.7	0.1	36.4	0.1	21.0

Source: calculated by the authors based on the State Statistics Service of Ukraine (n.d.) and the Ministry of Agrarian Policy and Food of Ukraine (n.d.)

In the first half of 2024, Ukraine has already exported 32.1 million tonnes of grain, which is 71.7% of the previous year's figure. The blocking of the Black and Azov Seas ports, partial resolution of this problem through the grain deal, and several large-scale challenges faced by farmers have forced them to intensify their search for alternative land and river grain sales channels. The enormous logistical challenges caused by the full-scale war had an impact on the volume and structure of grain exports. While in 2019-2021, the structure of wheat exports was steadily dominated by African countries with an average share of 36.4%, in 2023 this figure dropped to 11.5%. Before the war, more than 55% of wheat was exported to Asian countries. In 2022, this figure dropped to 37.9%, and in 2023 to 35.5%. The logistical transformation of wheat exports has shifted towards European countries. Before the war, the total share of wheat exports to European countries did not exceed 5%, while after the full-scale Russian invasion, it is approaching 50%. A similar trend is also evident in the second dominant export crop, corn (Table 2).

Table 2. Transformation of the structure of grain exports during the war, %

	2019		2020		2021		2022		2023		2024, the first half of the year	
	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%	thousand tonnes	%
Wheat												
Asia	10,705.1	53.5	10,069.3	55.8	10,944.6	54.5	4,247.8	37.9	5,738.9	35.5	4,458.7	41.3
Africa	7,730.6	38.6	6,079.8	33.7	7,393.1	36.8	2,369.4	21.1	1,855.9	11.5	1,869.5	17.3
Europe	533.4	2.7	695.3	3.8	332.1	1.7	4,250.4	37.9	7,803.8	48.3	4,463.3	41.4
USA	285.5	1.4	32.7	0.2	190.4	0.9	0.34	0.003	0	0	0	0
Corn												
Asia	10,690.7	33.1	11,824.6	42.4	12,545.1	50.8	7,871.6	31.6	7,095.8	26.9	3,204.5	16.2
Africa	5,983.9	18.5	4,695.2	16.8	3,502.9	14.2	2,190.1	8.8	3,624.8	13.7	2,900.1	14.7
Europe	15,092	46.7	6,818.1	24.4	8,068.3	32.7	14,605.9	58.5	14,983	56.8	13,666	69.1
USA	0	0	0	0	0	0	0	0	0	0	0	0

Source: calculated by the authors based on the State Statistics Service of Ukraine (n.d.) and the Ministry of Agrarian Policy and Food of Ukraine (n.d.)

During the war, the share of European countries importing corn from Ukraine increased to almost 60%, with an average of 29% coming from Asia and 11.2% from the African continent. At the same time, the loss of the cheapest export channel for grain products through seaports, with a corresponding alternative reorientation to land and river transport, affected domestic and foreign pricing policies on the grain market. Retrospective monitoring shows that in the first year of the war, the price situation in Ukraine's domestic grain market did not correlate with the catastrophic rise in fuel, fertilisers, other inputs and logistics costs. Compared to the pre-war period, average grain selling prices increased by only 1.8% (from 6,296.1 to 6,406.3 UAH/t). The selling price of wheat generally decreased by 5.1% (from 6,433.6 to 6,104.7 UAH/t), and barley by 4.1% (from 5,862.6 to 5,623.6 UAH/t). Corn for grain experienced a slight increase in price by 5.1% (Table 3).

Table 3. Average prices of grain crops sold by enterprises, over time, UAH per tonne, 2019-2024

Product name	2019	2020	2021	2022	2023	2024, the first half of the year	2022 to 2021, %	2023 to 2021, %
Cereals and pulses	3,867.5	4,794.1	6,296.1	6,399.7	5,675.5	7,189.3	101.6	90.1
of them								
wheat	4,077.1	5,017.5	6,433.6	6,097.1	4,970	8,250	94.8	77.3
grain corn	3,684.6	4,668.6	6,245.5	6,555.4	4,702	6,721	105.0	75.3
barley	3,932.5	4,352.7	5,862.6	5,632.7	3,755	6,597	96.1	64.1

Source: compiled by the authors based on the State Statistics Service of Ukraine (n.d.)

In 2023, the domestic price situation on the grain market had a steady downward trend, which pushed Ukrainian rural producers beyond the point of profitability. The average price of wheat did not exceed 5,000 UAH/t, which is 18.5% lower than in 2022 and almost a quarter less than the pre-war level. The domestic selling price of corn was 28.3% lower than in 2022, and barley lost another 33.3% in price compared to the pre-war period. The decline in domestic grain prices accelerated in late July 2023 after the grain corridor was closed.

At the beginning of 2024, prices for major crops were even lower compared to the same period in 2023: grade 3 wheat by 10% (5,700 UAH/t), grade 2 wheat by 8.1% (5,953 UAH/t), corn by 9.1% (5,570 UAH/t), barley by 13% (4,383 UAH/t), and spring wheat by 3.5% (6,298 UAH/t). During the same year, from January to mid-July, the purchase prices for wheat began to gradually increase by 47.4% for Grade 2 wheat (from 5,700 to 8,401 UAH/t), and by 37.6% for Grade 3 wheat (from 5,953 to 8,191 UAH/t). Since the beginning of the year, corn has risen in price by almost 21% or 1,151 UAH per tonne from 5,570 to 6,721 UAH/t. The price dynamics for barley and oats were even more pronounced. Since the beginning of the year, the purchase price of barley has increased by 50.5% from 4,384 to 6,597 UAH/t. Oats increased by 68.6% or 3,500 UAH/t from 5,100 to 8,600 UAH/t.

The result of the retrospective analysis of the dynamic series of price indicators in the markets of priority export crops of wheat and corn was the measurement of the proposed logistic coefficients of the price ratio K_1 and K_2 and their analytical comparison during 2009-2021 and the war. Thus, from 2009-2014, the world wheat price exceeded the domestic selling price, converted at the current exchange rate into the dollar equivalent, by an average of 1.5 times. In the next relevant period, from 2015 to 2021, the price equivalence of the wheat market is confirmed by the average value of the corresponding coefficient K_1 = 1.07. During the war, this coefficient, as an indicator of wheat market destabilisation, demonstrates that the world price exceeds the domestic purchase price by 2.2 and 2.3 times, respectively. The first half of 2024 preliminarily shows a decrease in this negative trend by 23.7% or from 2.28 to 1.74 points (Table 4).

Table 4. Retrospective dynamics of price correlation in the market of export-oriented grain crops

Year	Wheat					Corn				
	Average annual sales price, USD/t	Average annual export price, USD/t	Average annual global price, USD/t	Price-to-earnings ratios		Average annual sales price, USD/t	Average annual export price, USD/t	Average annual global price, USD/t	Price-to-earnings ratios	
				K_1	K_2				K_1	K_2
2009	119.8	138.0	223.4	1.87	1.15	126.7	141.1	165.5	1.31	1.11
2010	158.5	186.5	223.7	1.41	1.18	182.1	193.9	186.0	1.02	1.06
2011	213.4	261.2	316.2	1.48	1.22	240.6	254.0	291.8	1.21	1.06
2012	226.2	271.5	313.3	1.39	1.20	223.1	249.1	298.4	1.34	1.12
2013	231.7	243.7	312.2	1.35	1.05	219.9	229.1	259.0	1.18	1.04
2014	194.3	217.3	284.9	1.47	1.12	184.8	190.9	192.9	1.04	1.03
2015	159.5	166.4	204.5	1.28	1.04	163.4	157.6	169.8	1.04	0.96
2016	157.1	151.6	166.6	1.06	0.96	176.2	153.6	159.2	0.90	0.87
2017	176.8	159.4	174.2	0.99	0.90	167.4	154.1	154.5	0.92	0.92
2018	201.4	183.5	209.9	1.04	0.91	178.9	163.5	164.4	0.92	0.91
2019	200.7	182.7	201.7	1.01	0.91	166.1	161.3	170.1	1.02	0.97
2020	221.4	199.1	231.6	1.05	0.90	189.9	174.7	165.5	0.87	0.92
2021	290.8	252.8	315.2	1.08	0.87	239.8	238.8	259.5	1.08	1.00
2022	196.0	238.6	430.0	2.19	1.22	206.1	237.9	318.8	1.55	1.15
2023	149.1	182.1	340.4	2.28	1.22	163.4	188.4	252.7	1.55	1.15
2024 (first half of the year)	151.5	170.4	264.0	1.74	1.12	139.9	160.8	190.9	1.36	1.11

Source: calculated by the authors based on State Statistics Service of Ukraine (n.d.), Index Mundi Open Data Portal (n.d.) and Minfin (n.d.)

The logistic coefficient K_2, which demonstrates the ratio of the domestic purchase price of wheat to the export price, showed the following trend. Thus, in 2009-2014, the export price of grain traders exceeded the purchase price of producers by an average of 1.1 times, and in the following 2015-2021, this ratio decreased to 0.93. During the war, this indicator increased to 1.22. In the first half of 2024, compared to the previous year, 2023, there was an 8.2% decrease in the logistics burden from 1.22 to 1.12 points.

Compared to the wheat market, price distortions in the corn market were less pronounced. For example, the logistic coefficient of the ratio of the world and domestic purchase price during 2009-2014 averaged 1.18, while the K_2 coefficient was only 1.07. During 2015-2021, these indicators decreased to 0.96 and 0.94, respectively, and in 2016-2018 and 2020, the world price of corn was 8-13% lower than its domestic equivalent. A similar trend was established for the indicator of the ratio of domestic purchase and export prices of corn. During the war, the logistic coefficients of the ratio of world and export prices to domestic purchase prices increased by 1.55 and 1.15 points, respectively. The same is true for the wheat market: The first half of 2024 showed a decrease in logistics load factors by 12.3 and 3.5% (to 1.36 and 1.11 points, respectively). It is noted that the stability of the grain market is indirectly determined by the price situation and existing price fluctuations and ratios. The price has a fundamental impact on the category of efficiency of the grain production industry and forms an objective basis for the stability of economic activity and the prospects for the development of its producers.

The application of correlation analysis tools differentiated by types of grain crops and periods has established the following relationships. Thus, the pairwise correlation coefficients in the wheat market before the full-scale invasion are equal to: the dependent variable Y (domestic wheat price) with independent variables X_1 (world price) and X_2 (exchange rate) $R_{yx1} = 0.67$ and $R_{yx2} = 0.18$, respectively, and there is an anticorrelation between the independent factors themselves R_{x1x2}=0.44. Similar parameters in the corn market are equal to: R_{yx1}=0.77, R_{yx2}=-0.12, R_{x1x2} = -0.46. Therefore, a significant correlation between the domestic price of wheat and corn and the current dynamics of world prices for these crops is present at 44.9% and 59.2%, respectively. The impact of the exchange rate on the domestic selling price of wheat and corn was much lower at 3.3 and 1.5%, respectively (Table 5).

During the war, when the national economy and its agricultural sector experienced unprecedented global structural, production, logistical, and inflationary challenges, the parameters of the correlation between the factors under study were significantly transformed. Thus, the impact of world prices on domestic selling prices of wheat and corn increased to 54.8% and 73.5%, and the corresponding correlation coefficients increased to 0.74 and 0.86. At the same time, the impact of the devaluation factor (the exchange rate) increased in the wheat market to 47.7%, and in the corn market to 70.4%. There is a significant anticorrelation, or opposite relationship, between R_{yx1} = -0.68 and R_{yx1} = -0.84. Therefore, the more active the actual disappointing dynamics of the depreciation of Ukrainian national currency, the lower the domestic selling price for grain crops (wheat and corn).

The summarised results of the regression analysis used to study the impact of the dynamics of world prices and the national currency exchange rate on domestic sales prices of the main export-oriented grain crops (wheat and corn) before the full-scale invasion are presented in Table 6. The processing of the relevant dynamic series of actual parameters of domestic selling prices, world prices and the national currency exchange rate for the period from 1 January 2009 to 24 February 2022 determined the following parametric values of the multiple correlation coefficients: 0.86 and 0.81, respectively. Notably, there is a stronger relationship between the domestic selling price of grain and the combined effect of world prices and exchange rate dynamics, compared to the pairwise correlation.

Table 5. Comparison of correlation matrices before and during the war

Before the war (1.01.2009-24.02.2022)				**During the war (1.03.2022-1.07.2024)**			
Wheat				Wheat			
	Y	X_1	X_2		Y	X_1	X_2
Y	1			Y	1		
X_1	0.669902	1		X_1	0.74048	1	
X_2	0.18161	-0.44158	1	X_2	-0.69073	-0.81372	1
Corn				Corn			
	Y	X_1	X_2		Y	X_1	X_2
Y	1			Y	1		
X_1	0.7697	1		X_1	0.857201	1	
X_2	-0.12419	-0.45771	1	X_2	-0.83901	-0.74623	1

Source: calculated by the authors

Table 6. Resulting parameters of the correlation and regression analysis of the impact of world prices and the exchange rate on domestic sales prices of wheat and corn by farmers in Ukraine for the period 1.01.2009-24.02.2022

Equation	**Multiple correlation coefficient R**	**Determination coefficient R^2**	**Fisher's coefficient F-criterion**	**Student's t-test**	**Elasticity coefficients**
Wheat					
Y= -35.1583 + 0.7119X_1 + 3.1657X_2	0.856	0.732	Factual: 211.58 Tabular: 0.31	tx_1 = 20.10 tx_2 = 12.79	Ex_1 = 0.89 Ex_2 = 0.29

Table 6, Continued

Equation	Multiple correlation coefficient R	Determination coefficient R^2	Fisher's coefficient F-criterion	Student's t-test	Elasticity coefficients
Corn					
$Y = 31.9956 + 0.6555X_1 + 1.333X_2$	0.811	0.658	Factual: 149.28 Tabular: 0.42	$tx_1 = 17.08$ $tx_2 = 5.46$	$Ex_1 = 0.70$ $Ex_2 = 0.13$

Source: calculated by the authors

The coefficients of multiple determination indicate that the domestic selling price of wheat before the full-scale invasion depended on world prices and the UAH/USD exchange rate by 73.2%, and corn by 65.8%. 26.8% and 34.2% of the variation in the price parameters of wheat and corn, respectively, were determined by factors that were not covered by the scope of the research. The calculated values of the F-criteria (211.58 and 149.28) exceeded the specified table parameters with a probability of 0.95, which indicates the reliability of the built models. The corresponding test of the significance of the multiple correlation coefficients using the parametric tools of the Student's t-test proved that for both factors in the wheat and corn markets, with a probability of 0.95, there is a significant excess of the threshold parameter $t_{0.95}(158) = 1.98$. This confirms the significant significance of the influence of the selected factors. The formalised correlation and regression models of the dependence of domestic selling prices of wheat and corn on world prices and exchange rate dynamics are as follows:

$$Y_{wheat} = -35.1583 + 0.7119X_1 + 3.1657X_2; \quad (13)$$

$$Y_{corn} = 31.9956 + 0.6555X_1 + 1.333X_2, \quad (14)$$

where Y – theoretical value of the monthly selling price of wheat and corn by agricultural enterprises, USD/t; X_1 – monthly dynamics of world wheat and corn prices, USD/t; X_2 – USD/UAH exchange rate, UAH per USD.

The established correlation and regression dependencies interpreted the nature of changes in domestic sales prices of grain crops in Ukraine by farmers depending on the current dynamics of the relevant world prices and the exchange rate. For example, the model of wheat price dependence before the full-scale war, according to the calculations, suggests that an increase in the world price by USD 1 per tonne would lead to an increase in the domestic selling price by USD 0.71 per tonne, and an increase in the dollar exchange rate by UAH 1 would increase the price by USD 3.2. Similar calculations of the price dependence of corn show that an increase in the world price by USD 1 per tonne led to a corresponding increase in the realised price by USD 0.66 per tonne, and the growing dynamics of the exchange rate by UAH 1 per tonne increased the price by USD 1.33 per tonne.

A significant advantage (by 27.1%) of the price elasticity of wheat compared to corn was found. Thus, with a 1% increase in the global price of wheat, the domestic selling price increased by 0.89% in the analysed period. In turn, a similar increase in the world price of corn led to an increase in the domestic selling price by only 0.7% relative to the average values in the sample. The elasticity coefficients, which addressed the impact of the second factor (exchange rate), also showed a greater price sensitivity of wheat than corn. Thus, a 1% increase in the dollar led to a 0.29% increase in the selling price of wheat and only a 0.13% increase in the selling price of corn. The relevant results of the correlation and regression analysis used to determine the impact of the dynamics of world prices and the exchange rate on the domestic price situation in the wheat and corn markets during the war are presented in Table 7.

Table 7. Resulting parameters of the correlation and regression analysis of the impact of world prices on domestic sales prices of wheat and corn by farmers in Ukraine for the period 24.02.2022-1.07.2024

Equation	Multiple correlation coefficient R	Determination coefficient R^2	Fisher's coefficient F-criterion	Student's t-test	Elasticity coefficients
Wheat					
$Y = 173.1434 + 0.1944X_1 - 2.2635X_2$	0.756	0.571	Factual: 16.66 Tabular: 0.57	$tx_1 = 2.34$ $tx_2 = -1.16$	$Ex_1 = 0.43$ $Ex_2 = -0.50$
Corn					
$Y = 256.8268 + 0.3099X_1 - 4.6546X_2$	0.908	0.824	Factual: 58.71 Tabular: 0.19	$tx_1 = 4.14$ $tx_2 = -3.57$	$Ex_1 = 0.48$ $Ex_2 = -0.97$

Source: calculated by the authors

The corresponding study of the dynamic series of actual parameters of domestic selling prices, world prices for wheat and corn, and the national currency exchange rate during the war using correlation and regression tools has established that, compared to the pre-war period, the parametric value of the multiple correlation coefficient in the wheat market decreased by 6.2% from 0.86 to 0.76. At the same time, the same indicator of the strength of the factor relationship in the corn market increased by 12.3% from 0.81 to 0.91. In other words, the relationship between the domestic selling price and the combined effect of global prices and exchange rate movements decreased for wheat, while it increased significantly for corn.

In turn, the obtained parametric values of the coefficients of multiple determination during the war demonstrate the following dependence of domestic selling prices for grain crops on world prices and the USD exchange rate: for wheat by 57.1%, and for corn by 82.4%. In other

words, the geopolitical challenges faced by Ukraine's grain market have intensified the factor influence, which is difficult to measure parametrically and to process indicatively using economic and mathematical tools.

However, the influence of the factors selected for modelling remains significant, and the calculated values of the F-criteria (16.66 and 58.71) with a probability of 0.95 again exceed the determined table parameters, which indicates the reliability of the built models. Further verification of the significance of the multiple correlation coefficients using the parametric tools of the Student's t-test proved that the world price factor for both wheat and corn remains significantly above the threshold parameter $t_{0.95}(28) = 1.98$ with a probability of 0.95. In turn, the factor of exchange rate influence has acquired the opposite anticorrelation effect, with negative values of Student's t-tests: -1.16 and -3.57 respectively. In wartime, the correlation and regression models of the dependence of domestic sales prices of commodity producers on world prices and exchange rate dynamics are as follows:

$$Y_{wheat} = 173.1434 + 0.1944X_1 - 2.2635X_2; \quad (15)$$

$$Y_{corn} = 256.8268 + 0.3099X_1 - 4.6546X_2. \quad (16)$$

The identified correlation and regression dependencies of wartime suggest the following interpretation of transformational changes in the dependence of domestic grain prices on the actual dynamics of the relevant world prices and exchange rates: an increase in the price by 1 USD/t increased domestic selling price by 0.19 USD/t, which is 3.7 times less than in the pre-war period; a 1 UAH appreciation of the dollar reduces the domestic selling price of wheat by 2.26 USD/t; a 1 USD/t increase in the global corn price increased the sale price by 0.31 USD/t, which is half as much as in the pre-war period; a 1 UAH appreciation of the exchange rate reduces the sale price of corn by 4.65 USD/t.

In contrast to the pre-war period, the price elasticities of wheat and corn almost equalised during the war. As such, with a 1% increase in the global wheat price, the domestic selling price increased by 0.43% and 0.48%, respectively, between 24.02.2022 and 1.07.2024. In turn, the elasticity coefficients, which reflect the impact of the rising dollar, became negative. A 1% increase in the dollar during the war led to a 0.50% decrease in the selling price of wheat and a 0.97% decrease in the selling price of corn.

The calculation and analytical study of the developed correlation and regression models of the dependence of domestic sales prices of wheat and corn producers on world prices and exchange rate dynamics formulated theoretical values of the relevant price indicators (Figs. 1, 2). Clear periods of price imbalances in the markets of major export crops were identified. For example, in the wheat market in 2009-2014, there was a significant price disparity between the domestic selling price and the world price. The parameters of domestic wheat sales prices determined in the course of correlation and regression modelling relatively correct the monthly price dynamics.

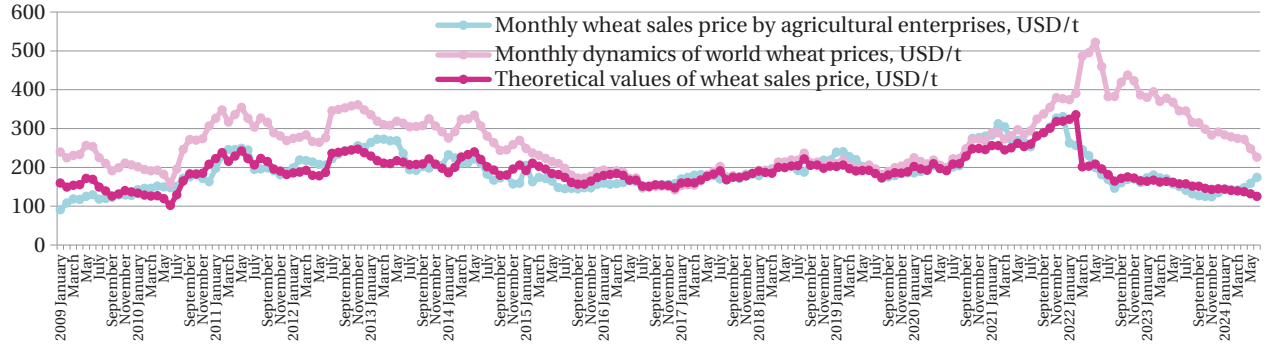

Figure 1. Graphical interpretation of the results of modelling the dependence of domestic wheat sales prices on the dynamics of world prices and the exchange rate

Source: calculated and compiled by the authors

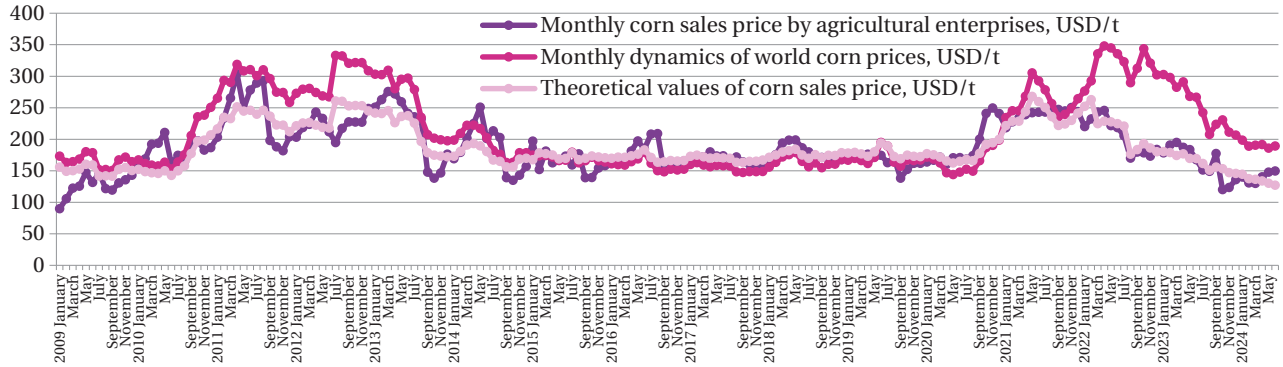

Figure 2. Graphical interpretation of the results of modelling the dependence of domestic corn sales prices on the dynamics of world prices and the exchange rate

Source: calculated and compiled by the authors

During 2015-2021, the price situation in the wheat market can be characterised as balanced, with domestic procurement prices practically in line with both global dynamics and certain theoretical parameters. During the war, which caused enormous problems with grain exports from Ukraine, which in turn held strong positions in the world market (Savosh *et al.*, 2020), the price imbalance became more pronounced, with world prices significantly exceeding both actual and theoretical levels of the purchase price of wheat in Ukraine. An identical periodisation of price imbalances was recorded in the corn market. The only difference is the relatively smaller variation in the excess of world prices over domestic sales prices both during 2009-2014 and during the war.

V. Skribans *et al.* (2024) identified and structured several problems faced by Ukrainian and global food markets, in particular wheat and corn producers. The authors demonstrated the need for an adaptive search for new logistics solutions to ensure the functioning of the grain market. It is worth noting that the Black Sea Grain Initiative has contributed to further grain exports from Ukraine and slowed the pace of global food price growth. Furthermore, the proposal to create a transport corridor for Ukrainian agricultural products through the territory of the EU, using the Baltic Sea shipping routes, is considered rational. The results of the study by H.M. Ay & A. Söylemez (2023), which emphasised the importance of Turkey's geopolitical and diplomatic efforts in signing the grain agreement and ensuring the functioning of the Black Sea grain corridor as the main alternative to the export logistics disrupted by the war.

A.M. Martins (2024) analysed the short-term price response of the global grain market in the context of the Russian-Ukrainian war and different periods of the Black Sea Grain Agreement. Following the study, the outbreak of war and periods of non-renewal of the Black Sea Grain Agreement significantly reduced-price indicators in the grain market, with supply constraints leading to a substantial price increase. A. Rose *et al.* (2023) conducted their study using the computable general equilibrium model of the Global Trade Analysis Project (GTAP). The authors analysed the economic consequences of destructive changes in Ukrainian grain exports caused by a full-scale war. Based on the modelling results, disruptions and violations in the export sector negatively affect not only Ukraine and the aggressor country but also cause significant negative economic consequences in other regions of the world. However, there are certain concerns regarding the comparative results of forecasting the losses of real GDP in Ukraine and Russia as a result of deteriorating conditions and opportunities for grain exports.

F. Urak (2023) determined that price volatility in the grain market poses a significant threat to the food security of many countries. The author assessed the degree of risks associated with the pandemic and the Russian-Ukrainian war and their impact on critical agricultural markets in Turkey: wheat, barley, corn, and sunflower oil. The author used the VAR (1)-Asymmetric BEKK-Generalised Autoregressive Conditional Heteroscedasticity (GARCH) (1.1) model. The study established that the combination of short- and long-term uncertainties negatively affects the profitability of participants in critical markets, in particular, grain crops.

R. Ihle *et al.* (2022) quantified how the full-scale war in Ukraine has affected price imbalances in global commodity markets. Using a coherence index, the authors conducted a retrospective analysis of 15 key global indices and identified the impact of logistics disruptions on the growing dynamics of grain, energy and fertiliser prices and the creation of global threats to food and energy security. Following the results of the study, it is necessary to increase the resilience of global food supply chains during economic disasters and wars.

S. Jagtap *et al.* (2022) investigated the nature and extent of the impact of the Russian-Ukrainian war on the efficiency of global food supply chains, including grain. The PRISMA approach (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used to formulate a set of priority tactical and strategic decisions that could minimise the negative impact of the war on the global food supply system. However, the authors' position on the need to find alternative partners for the supply of grain and other food is considered controversial.

The results of a study by A.K. Mottaleb *et al.* (2022) are notable for their methodology of studying price imbalances in the grain market. The authors determined the potential impact of the Russian-Ukrainian war on the dynamics of wheat prices and consumption, both in physical terms and in terms of calories. The authors determined that a 1% decrease in global wheat trade could lead to a 1.1% increase in the producer price. A 1% increase in the producer price, in turn, could reduce per capita wheat consumption by 0.59% per year. Following the authors, a 50% reduction in wheat exports from Ukraine and Russia could lead to a 15% increase in wheat prices and an 8% reduction in wheat consumption.

S. Ishchuk & L. Sozanskyy (2024) assessed the impact of the war on the dynamics and structure of merchandise exports from Ukraine. The study determined that the commodity orientation of Ukrainian exports (grains, oilseeds) increased significantly during the war. As one of the scenarios for the post-war development of the country's agricultural export potential, the authors propose to partially reorient grain exports to livestock production and increase its exports. Also promising for the post-war recovery of Ukraine's agrarian economy are the results of a study by T. Ostashko *et al.* (2023). The authors emphasised the need to optimise the grain market, aimed at reducing the volume of grain exports as a raw material and increasing the export potential of its processed products.

As a result of the current study is verified methodical calculation and constructive algorithm for studying the price situation on the grain market of Ukraine in the conditions of war, which, as opposed to the existing ones, comprehensively covers a set of indicators for assessing structural transformations and priority problems of grain exports and tools for correlation and regression modelling to determine the impact of the dynamics of world prices and exchange rate fluctuations on the volatility of domestic sales prices of wheat and corn in rural areas. The study of the impact of world prices and the exchange rate in peacetime in the face of logistical and inflationary challenges and the transformations of these factors in the context of the war on pricing in the grain industry is important for government agencies in forecasting grain prices and grain production efficiency.

▸ Conclusions

The study identified price imbalances and an analytical and indicator summary of the results of variable modelling of the factor impact of world prices and exchange rate dynamics on the actual prices of wheat and corn at which rural producers sell their products. The study has established significant structural and logistical transformations that took place in the field of grain exports during the war. Compared to the pre-war period, in 2022, natural exports decreased by 12.3 million tonnes (or 24.2%). In 2023, after the logistical problems were relatively resolved, these figures were 6.0 million tonnes and 11.8%, respectively. During the first year of the war, export revenues from grain sales fell by 3.2 billion USD, or 26.2%, and in 2023, the decrease in cash receipts from grain exports exceeded 4 billion USD compared to 2021.

The study determined that before the war, the main importers of wheat and corn from Ukraine were Asian countries, with an average share of 55 and 42.1%, and African countries with a share of 36.4 and 16.5%, respectively. The risk of Russian shelling of transport vessels in the Black Sea led to a decrease in the share of exports to the Asian region in 2022 to 37.9%, and in 2023 to 35.5%, and corn to 31.6 and 26.9%; to the African region to 21.1 and 11.5%, and to 8.8 and 13.7%, respectively. The reorientation of grain logistics to land and river transport increased the share of European countries in Ukraine's wheat and corn exports in 2023 to 48.3% and 56.8% but negatively affected domestic and international grain market prices. Domestic wheat prices in 2023 dropped by 22.7% and corn prices by 28.2%.

The established price imbalances using the tools of logistic coefficients K_1 and K_2 demonstrate the destabilisation of the grain market: in wartime, world prices exceed domestic selling prices for wheat by 2.2-2.3 times, and for corn by 1.55 times, while the corresponding indicators for export prices are 1.22 and 1.15. The development of correlation analysis tools for the chosen variable periodisation revealed a significant increase in the factor influence of the dynamics of world prices on domestic selling prices of wheat and corn from 44.9 and 59.2% to 54.8 and 73.5%, respectively, in the context of the war. In turn, the impact of the exchange rate on the domestic selling price of wheat and corn increased dramatically from the pre-war levels of 3.3 and 1.5% to 47.7 and 70.4%, with a proven anti-correlation and negative impact.

The modelling shows that before the full-scale Russian invasion, a 1 USD/t increase in the world wheat price led to a 0.71 USD/t increase in the domestic selling price, a 1 UAH appreciation of the dollar increased the price by 3.2 USD/t, and for corn, these indicators were 0.66 and 1.33 USD/t, respectively. In the context of war, a 1 USD/t increase in the global price leads to a 0.19 and 0.31 USD/t increase in the domestic price of wheat and corn, respectively, while a 1 UAH devaluation reduces the domestic selling price by 2.26 and 4.65 USD/t, respectively. Further research should analyse the forecasting of the pricing process and performance indicators of the internal and external components of the grain market, considering the objective influence of logistics transformations, world prices and the exchange rate.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Оцінка структурних змін експорту та цінової ситуації на ринку зерна України в умовах війни

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▸ **Анотація.** Метою дослідження була оцінка основних проблем експорту, індикативне вимірювання цінових диспропорцій на ринку зерна та порівняльний аналіз впливу світових цін та динаміки валютного курсу на внутрішні ціни реалізації пшениці та кукурудзи до і під час війни. Було використано такі методи: порівняльного аналізу, статистичний, табличний, графічний, розрахунково-конструктивний, абстрактно-логічний, а також інструментарій кореляційно-регресійного аналізу. Встановлено значну структурну трансформацію експорту пшениці та кукурудзи під час війни – майже дворазове зниження частки азійських країн та зростання питомої ваги країн Європи в експорті пшениці від 1,7 до 48,3 %, а кукурудзи – від 32,7 до 56,8 %. Визначено негативний вплив логістичної трансформації експорту на внутрішні і зовнішні ціни на ринку зерна. Порівняно з довоєнним періодом внутрішні ціни на пшеницю та кукурудзу впали на 22,7 та 28,2 %. Індикативне визначення цінових диспропорцій довело, що до війни світові ціни на пшеницю та кукурудзу майже відповідали внутрішнім значенням, а під час війни дане співвідношення збільшилось до 2,2 та 1,6 разів відповідно. Моделюванням встановлено, що до війни збільшення світової ціни пшениці на 1 дол. США/т призводило до еквівалентного зростання внутрішньої реалізаційної ціни на 0,71 дол. США/т, а зростання курсу долара на 1 грн. збільшувало ціну на 3,2 дол. США. В умовах війни вплив обраних факторних ознак кардинально змінився – відповідне збільшення світової ціни пшениці на 1 дол. США/т призводить до зростання внутрішньої реалізаційної ціни всього на 0,19 дол. США/т, що в майже в 4 раза менше, ніж у мирний час, а зростання курсу долара на 1 грн. зменшує внутрішню ціну реалізації 1 т пшениці на 2,26 дол. США. Відповідний вплив зростання світової ціни на кукурудзу на її внутрішній показник під час війни зменшився вдвічі – від 0,66 до 0,31 дол. США/т, а зростаюча динаміка валютного курсу на 1 грн. зменшує ціну реалізації кукурудзи на 4,65 дол. США/т

▸ **Ключові слова:** світова ціна; валютний курс; цінові диспропорції; цінова еластичність; моделювання впливу

Received: 27.10.2024. Revised: 02.02.2025. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.63

Ekonomika APK, 32(2), 63-75

UDC 631.164:004.9

Digital farming platforms as a tool for strengthening cooperation between Kyrgyzstan and China: Potential and prospects

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► **Abstract.** The purpose of this study was to assess the role of digital agricultural platforms in strengthening economic cooperation between Kyrgyzstan and China, focusing on their potential to increase agricultural productivity, resources optimisation, and farmers' access to markets expansion. The methodology involved analysing primary and secondary sources, conducting structured interviews with experts, examining trade data between Kyrgyzstan and China from 2001 to 2023, and evaluating barriers and opportunities for digitalisation in the agricultural sector. The results indicated that digital agricultural platforms contributed to improved logistics, enhanced efficiency in managing agricultural processes, and facilitated international cooperation. Kyrgyzstan's exports to China increased from USD 50 million in 2001 to USD 900 million in 2023, while imports reached USD 3.6 billion, demonstrating the economic interdependence between the two countries. The adoption of digital solutions, including Internet of Things, artificial intelligence, and blockchain, minimised costs, enabled yield forecasting, and improved supply chains. The findings of the study indicated that the digitalisation of Kyrgyzstan's agricultural sector had the potential to significantly enhance its competitiveness and promote sustainable economic development. However, several challenges needed to be addressed, including financial constraints, underdeveloped digital infrastructure, and the

► **Suggested Citation**: Adamkulova, Ch., Akylbekova, N., Omurova, S., Mambetova, A., & Mambetkazieva, N. (2025). Digital farming platforms as a tool for strengthening cooperation between Kyrgyzstan and China: Potential and prospects. *Ekonomika APK*, 32(2), 63-75. doi: 10.32317/ekon.apk/2.2025.63.

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necessity to align government policies with the digital economy. The successful implementation of digital solutions required a comprehensive approach that encompassed both technological modernisation and the development of farmers' competencies to effectively utilise innovative tools

▸ **Keywords:** agriculture; technology adoption; supply chain; blockchain; food security

▸ Introduction

Agriculture is central to the national economy of Kyrgyzstan, contributing an estimated one-third of the country's gross domestic product. China is Kyrgyzstan's largest trading partner in Central Asia and abroad. As in Kyrgyzstan, in China agriculture is one of the main types of economic activity and plays an important role in the welfare of the population. Both countries have significant competitive advantages in agricultural production. Both countries are interested in partnership to promote sound agricultural economic actions between them, combining production and supply advantages to achieve complementary benefits. The Digital Farming Platform concept is a systemic, technology-based approach to create a more inclusive and transparent value chain for local agricultural systems. The Digital Farming Platform focuses on building digital and physical infrastructure that connects value chains both economically and socially.

The use of Internet of Things (IoT) technologies and decision-making systems in agriculture needs to be improved in 2025. C. Cambra Baseca *et al.* (2019) investigated the potential of IoT to optimise field management, showing the effectiveness of sensor networks and machine learning algorithms for irrigation, fertilisation, and yield. However, their study does not take into account the adaptation of these systems to different climatic conditions and regions with weak infrastructure. Kyrgyzstan faces challenges in agricultural productivity due to its dependence on food imports and regional conflicts. Z.A. Musarova & C.U. Adamkulova (2023) explored the country's economic vulnerabilities, focusing on food security. The existing literature highlights the reliance on imports, making Kyrgyzstan vulnerable to external shocks.

The problem addressed in study by B. Xu (2021) is the lack of comprehensive analysis on the long-term impacts of educational initiatives within China's Belt and Road Initiative on the development of partner countries. He explores how education policies, including international collaborations and cultural exchanges, contribute to China's regional influence and cooperation. The study reveals that education diplomacy plays a key role in China's foreign policy, enhancing bilateral relations and fostering mutual understanding.

The small scale of agriculture and limited access to modern technologies often lead to a significant gap between large and small farms in the context of digital technologies (Bekmuratov *et al.*, 2025). L. Xie *et al.* (2021) studied the impact of digital technologies on small farmers in China, where technologies have helped to increase production efficiency, but their adoption is limited due to insufficient access to infrastructure and financial resources.

The use of digital reporting platforms in Environmental, Social and Governance Strategy implementation enhances transparency and investor confidence. O. Lagodiyenko (2024) analysed their benefits, including automated data collection, analysis, and integration with management systems, highlighting their role in optimising processes and reducing errors. The expansion of digital technologies in agriculture improves production efficiency, resource optimisation, and environmental impact. R. Savkov & N. Karvatska (2024) examined the use of IoT, big data, automation, and robotics, proving their role in productivity and yield growth.

Integration of the digital economy into agriculture contributes to modernisation and efficiency. J. Guo & J. Lyu (2024) investigated the relationship between the digital economy and the development of China's agricultural sector using panel data from 31 provinces and spatial autocorrelation models. The authors found that digitalisation improves productivity and coordination between producers, but the development of digital infrastructure outpaces the adaptation of the agricultural sector. At the same time, significant regional disparities remain and the spatial impact of the digital economy on agricultural production is not well understood.

Digital technologies increase the efficiency of agriculture by optimising production processes (Wrzecińska *et al.*, 2023). M. Anitei *et al.* (2021) explored the prospects for digital farming by analysing the use of IoT, big data, and robotic systems. A survey of farmers revealed key barriers: lack of personnel, financial constraints, and high cost of technology. At the same time, the long-term economic impact of digitalisation on small farms has not been sufficiently considered.

The purpose of this study was to assess the impact of digital platforms on the development of the agricultural sector of Kyrgyzstan and China, to determine their role in improving economic cooperation between the countries and to outline the prospects for their further implementation to strengthen international cooperation. The objectives of the study were to analyse the current state of use of digital technologies in agriculture in Kyrgyzstan and China, identifying key trends and challenges; to study the economic, technological and political aspects of cooperation between the countries in the field of digital.

▸ Materials and methods

This study was applied interdisciplinary research with elements of descriptive and analytical approaches. It covered the economic, technological, and environmental aspects of digital agricultural platforms in the context of agricultural development in Kyrgyzstan and China. The surveys were conducted between January and December 2024, gathering data from stakeholders in the agricultural sector in both Kyrgyzstan and China. The tools studied included the IoT for collecting data from sensors, Artificial Intelligence (AI) for analysis and decision-making, big data for improving resource management and forecasting, robotics (drones, robotic systems) for process

automation, blockchain for ensuring transparency of product supply, smart contracts for automating transactions, and cloud services for data storage (Kumar *et al.*, 2024; Mussa, 2024). The choice of these tools was based on their ability to increase production efficiency, reduce costs, ensure the sustainability of the agricultural sector, and support international cooperation.

The data used in this study were derived from a combination of primary and secondary sources, carefully selected to provide a holistic understanding of digital farming platforms and their potential role in Kyrgyz-Chinese agricultural cooperation. Primary data were collected through direct engagement with stakeholders in the agricultural sector in Kyrgyzstan and China, with 30 participants in total. The sample included agricultural experts, policymakers, and farmers, selected based on their experience in managing agricultural projects, implementing or advising on digital technologies in agriculture (such as the IoT, AI, or precision agriculture), and their involvement in the development or implementation of agricultural policies or digital transformation strategies. In Kyrgyzstan, the research focused on the Naryn and Chui provinces, where smallholder farmers were involved in agricultural practices and faced varying levels of digital readiness. The experts were categorised as follows: 12 agricultural experts (5 from research institutes, 4 from non-governmental organisations, and 3 from government agencies), 10 farmers, and 8 policymakers. The gender distribution was 60% male and 40% female, ensuring a diverse range of perspectives on digital technology adoption in agriculture. The aim of the interviews was to assess the state of digital readiness among smallholder farmers in Kyrgyzstan and the barriers they faced in adopting new technologies. First-hand accounts helped identify challenges and opportunities from the perspective of those directly involved in agriculture. Sample questions included: How would you assess the digital readiness of farmers in your region? What barriers hinder the adoption of digital farming technologies? What role should the government play in promoting digital agriculture? Ethical standards such as the Belmont Report were followed, with participants informed about the study's purpose and ensuring confidentiality (U.S. Department of Health and Human Sciences, n.d.). Consent was obtained from all participants, who were assured that their responses would be anonymised and used solely for research purposes.

The selection of secondary data sources was based on their relevance to understanding the trade and agricultural relationship between Kyrgyzstan and China. Key government documents, such as the Protocol on Phytosanitary Requirements for the Export of Beans from the Kyrgyz Republic to the People's Republic of China between the Ministry of Water Resources, Agriculture and Processing Industry of the Kyrgyz Republic, provided insights into the agricultural export regulations applicable to Kyrgyzstan's trade (Kyrgyzstan and China…, 2025). Additionally, reports from international organisations like China, Kyrgyzstan agree Belt and Road Initiative key to bilateral ties, regional cooperation offered context on broader economic frameworks, such as the Belt and Road Initiative, that influenced agricultural trade (Bo, 2019). These sources combined regulatory, policy, and economic insights.

The interview data were processed using a qualitative method of analysis, in particular, content analysis. This method allowed for the systematisation of the respondents' answers, identification of key themes and trends, and determination of barriers and opportunities in the process of introducing digital platforms in the agricultural sector. Research methods for digital platforms and tools included an analysis of existing digital solutions, such as precision farming platforms, tools for monitoring and forecasting yields, and integration with databases for monitoring weather conditions and soil indicators. To study the impact of digital technologies on the agricultural sector, comparative analysis methods were also used to assess the effectiveness of different platforms in Kyrgyzstan and China, as well as economic analysis methods to determine the impact of digitalisation on productivity and cost reduction.

The analysis was based on historical trade data between Kyrgyzstan and China from 2001 to 2023, sourced from official government statistics (Observatory of Economic Complexity, n.d.). The period from 2001 to 2023 was selected because it encompassed key developments in trade relations, including the implementation of major bilateral agreements and the growing influence of initiatives such as the Belt and Road Initiative, which had shaped the economic dynamics between the two countries. These materials provided a comprehensive overview of trade dynamics, including export and import volumes, which were used to assess the impact of digital transformation on bilateral agricultural trade flows. The study also involved a SWOT analysis, identifying the key strengths, weaknesses, opportunities, and threats related to the digitalisation of the agricultural sector in Kyrgyzstan and China. Based on these findings, a set of strategic recommendations was developed to address the risks, such as technological barriers, financial constraints, and regulatory challenges, and to promote the sustainable adoption of digital farming technologies. By integrating multiple research methods, the study provided a comprehensive evaluation of digital agriculture's potential in Kyrgyzstan and China, offering insights into both the opportunities and challenges associated with agricultural digitalisation.

▸ Results

Digital agricultural platforms are crucial for modernising agriculture, ensuring efficiency and transparency while integrating advanced technologies like AI, IoT, big data, and blockchain. These platforms optimise agricultural processes, helping enterprises manage production cycles, increase yields, and reduce resource costs. In a globalised environment, digital technologies facilitate international cooperation, simplify trade, and create a shared information space for market participants.

IoT devices track essential parameters like temperature and soil moisture, providing real-time data that enables more efficient use of resources. Big data and analytics process large data volumes, enhancing resource efficiency, soil conditions, and yield forecasts. Automation, including drones and robotic systems, improves

productivity and reduces losses (Kumar *et al.*, 2024). AI systems help with precise decision-making, such as pest detection and water optimisation, while blockchain ensures transparency and reduces fraud, improving trust and automating transactions through smart contracts. Digital platforms support sustainable development, resource efficiency, and productivity, and facilitate international cooperation through data sharing and unified trade chains (Mussa, 2024).

The development of 5G and cloud technologies is key for expanding digital platforms in remote areas, allowing small farms to adopt innovative solutions. Continued advancements in AI and automation further improve agricultural activities and forecasting accuracy, enhancing productivity and supply chain transparency. However, the widespread adoption of digital agriculture faces obstacles like high technology costs, limited digital literacy, poor infrastructure, and cybersecurity threats (Mandal *et al.*, 2024). Regulatory restrictions and inconsistent international standards complicate the global implementation of digital technologies in agriculture. To overcome these barriers, government support, private investment, and increased technology accessibility are essential. Digital transformation can be accelerated by improving farmer education, creating safe cloud services, and enhancing internet access in rural areas (Nehrey, 2023). Trade relations between Kyrgyzstan and China, dating back to the Great Silk Road, have evolved significantly. Since Kyrgyzstan's independence, trade turnover has increased from USD 500 million in 2001 to over USD 4.5 billion in 2023, underscoring the importance of their economic partnership, particularly in agriculture (Observatory of Economic Complexity, n.d.). Despite growth, Kyrgyzstan's trade balance has shifted to a deficit, mainly due to high imports from China. This growing dependence highlights the need for Kyrgyzstan to develop domestic industries and boost exports. A key step is leveraging digital farming platforms and technology to enhance agricultural productivity, processing, and competitiveness in international markets.

Kyrgyzstan and China have signed agreements on agricultural trade cooperation, covering quarantine, food safety, and health protocols. Notably, the Protocol on Phytosanitary Requirements for the Export of Beans from the Kyrgyz Republic to the People's Republic of China between the Ministry of Water Resources, Agriculture and Processing Industry of the Kyrgyz Republic and the General Administration of Customs of the People's Republic of China ensures quality control and product safety, opening up opportunities for expanding Kyrgyz exports (Kyrgyzstan and China…, 2025). Investment projects, such as milk processing plants in Chon-Korgon and Naryn, aim to modernise agriculture by attracting investment and reducing raw material exports. Additionally, under the "One Belt, One Road" initiative (Bo, 2019), A Memorandum of understanding was signed between the Ministry of Economy and Commerce of the Kyrgyz Republic, the State Development Bank and the Silk Road Foundation (China) (2024) to develop agricultural trade infrastructure, enhancing the competitiveness of Kyrgyz agriculture by improving logistics and processing capacities. This agreement strengthens cooperation, facilitating access to the Chinese market and supporting agricultural sustainability.

From 2001 to 2023, trade turnover between Kyrgyzstan and China has demonstrated a consistent upward trend, highlighting the strengthening economic ties between the two countries. Kyrgyz exports to China have shown a steady increase, growing from USD 50 million in 2001 to USD 900 million in 2023 (Observatory of Economic Complexity, n.d.). These exports primarily consist of raw agricultural products, livestock, and food commodities, reflecting Kyrgyzstan's strong agricultural base. However, a gradual transition toward value-added processing has been observed, which presents an opportunity to further enhance the competitiveness of Kyrgyz exports in the Chinese market. Strengthening production facilities and investing in processing technologies can allow Kyrgyz exporters to move up the value chain and capture a greater share of the market. Imports from China have also risen substantially, reaching USD 3.6 billion in 2023. A significant portion of these imports includes machinery, electronics, textiles, and construction materials, illustrating Kyrgyzstan's reliance on Chinese goods across various industries. This increasing dependence on Chinese imports raises concerns about long-term economic sustainability and underscores the need for Kyrgyzstan to bolster its domestic manufacturing and industrial capabilities to achieve a more balanced trade structure.

Despite the growth in exports, trade between the two countries remains asymmetrical, with Kyrgyzstan's imports consistently exceeding its exports, leading to a persistent trade deficit. Addressing this imbalance requires targeted efforts to diversify the country's export portfolio, promote industrialisation, and strengthen the logistics infrastructure to facilitate trade expansion. Investments in processing industries, modernisation of supply chains, and trade facilitation policies could contribute to reducing the trade deficit while enhancing the competitiveness of Kyrgyz products in the Chinese market. Given the increasing importance of agriculture in Kyrgyzstan-China trade relations, integrating digital solutions can significantly enhance efficiency and sustainability. Digital farming platforms, IoT-based farm management systems, and blockchain-enabled supply chains can improve productivity and create direct market access for Kyrgyz farmers. Moreover, strengthening investment in smart agricultural infrastructure will allow Kyrgyz producers to compete more effectively in the Chinese market.

To fully capitalise on these opportunities, Kyrgyzstan must prioritise policy harmonisation, financial incentives for digital agriculture, and cross-border collaboration in agritech. Continued cooperation between the two countries will not only enhance economic ties but also contribute to regional food security and agricultural innovation. Figure 1 illustrates the evolution of trade relations between Kyrgyzstan and China from 2001 to 2023, showing a steady increase in trade turnover, particularly with an increase in Kyrgyzstan's exports and imports. This visual representation highlights the growth and trade dynamics between the two countries, underlining the significance of agricultural trade.

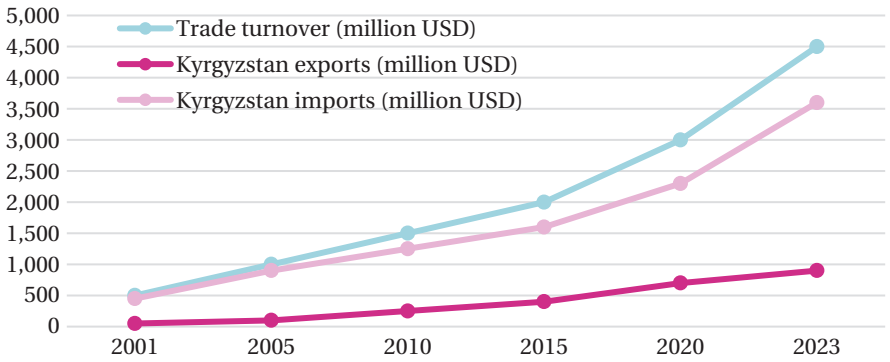

Figure 1. Trade dynamic between Kyrgyzstan and China 2001-2023
Source: created by the authors based on Observatory of Economic Complexity (n.d.)

Kyrgyzstan and China have developed a strong economic partnership, with agriculture playing a pivotal role in their bilateral trade relations. However, to ensure long-term sustainability and balanced trade growth, Kyrgyzstan must focus on increasing domestic production capacity, enhancing agricultural processing industries, and reducing import dependency. Leveraging digital farming platforms and modern agricultural technologies will be essential in achieving these objectives.

By fostering continued cooperation in research, investment, and policy alignment, both nations can maximise the benefits of their agricultural trade relationship. Strengthening trade agreements, expanding digital agricultural initiatives, and improving market access will be key drivers of economic growth and regional stability in the coming years. The trade dynamics shown in the Figure 1 emphasise that Kyrgyzstan needs to use strategic tools such as digital agricultural platforms to increase export potential. By improving agricultural productivity, developing value-added processing, and increasing access to international markets, Kyrgyzstan can create a more balanced trade relationship with China. The introduction of digital tools can also help improve the transparency and efficiency of the agricultural value chain, making Kyrgyzstan's exports more competitive.

Digitalisation contributes to the development of the agricultural sector by automating management processes, improving access to market data, optimising resource use, and increasing production efficiency (Khamzaeva *et al.*, 2020). Platforms for precision farming, soil, weather and yield data analysis help farmers make informed decisions, which in turn increases productivity and reduces costs. They also provide more convenient conditions for financing through digital platforms and microcredit, providing access to digital financial services for small farmers.

Trade cooperation between Kyrgyzstan and China, in particular in the agricultural sector, is actively developing through the use of digital technologies. Many of the agreements signed, such as the Protocol on Phytosanitary Requirements for the Export of Beans from the Kyrgyz Republic to the People's Republic of China between the Ministry of Water Resources, Agriculture and Processing Industry of the Kyrgyz Republic and the General Administration of Customs of the People's Republic of China, include standards for digital monitoring of product quality and transparency in supply chains (Osmonalieva, 2025). The relationship between digitalisation and trade cooperation is manifested in the fact that digital platforms help to develop new business opportunities, reduce the cost of transportation, storage and processing of products, which increases exports, in particular to China (Bekmuratov *et al.*, 2024).

To better understand the level of digital readiness in Kyrgyzstan's agricultural sector, in-depth interviews were conducted with a total of 30 participants, including farmers, agricultural experts, and policymakers from the Naryn and Chui oblasts. The goal was to identify the barriers to the adoption of new digital technologies in agriculture and to gain insight into the challenges faced by smallholder farmers in these regions. The data gathered highlighted that a significant portion of farmers, about 70%, expressed a keen interest in using digital platforms to improve their agricultural practices. They recognised the potential benefits of digital solutions in increasing productivity, enhancing efficiency, and reducing operational costs. However, the majority of the respondents (80%) pointed out several obstacles that hindered their ability to adopt these technologies.

The key challenges identified included a lack of necessary infrastructure, particularly in rural areas where internet access remains limited. Over 60% of farmers mentioned that unreliable or insufficient internet coverage in remote regions made it difficult to utilise digital farming tools effectively. Another critical barrier was the high cost of technology and equipment, with 75% of farmers stating that the initial investment required for digital solutions such as precision farming tools, sensors, and automation systems was beyond their financial capacity. Furthermore, low levels of digital literacy were cited as a major obstacle by 70% of the respondents, indicating that many farmers struggle to understand and operate digital tools effectively.

These findings were also corroborated by the opinions of agricultural experts, who stressed that the successful implementation of digital solutions in agriculture requires significant state-level support. Experts emphasised that the government should take a proactive role in providing incentives for technology adoption, such as subsidies for equipment and financial assistance for smallholder farmers. Additionally, they highlighted the importance of creating training programmes tailored to farmers' needs,

aiming to boost their digital literacy and technical skills. Without such support, many farmers remain reluctant to embrace new technologies.

The findings from the interviews revealed that 70% of the farmers surveyed expressed interest in using digital platforms, with 65% recognising the potential benefits of digital tools in increasing efficiency, improving market access, and reducing operational costs. However, 85% of farmers cited significant barriers to adoption, including a lack of necessary infrastructure (with many rural areas facing limited internet access), high technology costs, and low levels of digital literacy. Agricultural experts also emphasised that, while farmers showed enthusiasm for digital technologies, there was a critical need for government support. They noted that financial incentives, such as subsidies for technology and equipment, along with targeted training programmes to increase digital literacy, would be essential for facilitating the widespread adoption of digital farming solutions.

In November 2024, China unveiled a five-year action plan aimed at accelerating the digital transformation of its agricultural sector. This plan includes establishing a national agricultural big data platform by 2028, which will enhance efficiency across farms, livestock, and fisheries (Morchid *et al.*, 2024). Despite the numerous advantages, the implementation of digital farming platforms in Kyrgyzstan faces several obstacles. One of the primary challenges is the lack of sufficient digital infrastructure, particularly in rural areas, where limited internet access restricts the full utilisation of digital tools. Farmers who rely on traditional agricultural methods often exhibit resistance to adopting new technologies, further complicating the transition to digitalised farming (Uzenbaev *et al.*, 2019). Additionally, financial constraints, such as the high upfront costs associated with acquiring digital equipment, make it difficult for smallholder farmers to invest in these platforms without government support or external funding.

Policy-related challenges also hinder the widespread adoption of digital solutions in Kyrgyzstan. The absence of a supportive regulatory framework and high tariffs on digital components increase the costs associated with technology integration. Moreover, cultural differences in decision-making and resource utilisation between Kyrgyz and Chinese agricultural stakeholders can create further complexities. Overcoming these challenges requires coordinated policy efforts, financial incentives, and structured training programmes to facilitate a smoother transition toward digital agriculture.

The expansion of digital platforms in Kyrgyzstan and China offers opportunities to improve productivity, market access, and supply chain management. Digital solutions like online trading platforms, precision farming, and digital payment systems provide valuable data on soil, climate, and crop health, leading to better resource use and increased yields. However, challenges like limited digital infrastructure in rural Kyrgyzstan, complex land ownership regulations, and resistance from traditional farming methods hinder adoption. Financial constraints, high equipment costs, and tariffs further complicate the transition to digital farming.

Cultural and organisational factors also impede implementation, as decision-making within farming communities is influenced by traditional hierarchies. The lack of specialised training in digital agriculture prevents farmers from fully utilising these platforms. Addressing these challenges requires investments in rural broadband, financial support, and educational initiatives to increase digital literacy. Collaboration between Kyrgyz and Chinese institutions can accelerate the adoption of digital farming and create a more efficient agricultural sector.

Digital farming platforms hold immense potential to transform agriculture and strengthen bilateral cooperation between Kyrgyzstan and China. By integrating advanced technologies such as IoT, AI, blockchain, and big data, these platforms can modernise agricultural practices, optimise resource use, and improve productivity. This research highlights the significant economic and social benefits of adopting digital farming platforms in Kyrgyzstan, including enhanced market access, sustainable farming practices, and increased export capacity. For China, these platforms provide a reliable supply of high-quality agricultural products and expand the Belt and Road Initiative's influence in Central Asia (Bo, 2019). In order to further develop recommendations for the implementation of digital agricultural platforms between Kyrgyzstan and China, it is necessary to assess the strengths, weaknesses, opportunities, and threats that exist for each party. These aspects that determine the potential for cooperation and development are presented in Table 1. The recommendations were developed based on the results of surveys conducted among farmers, agricultural experts and policy makers in Kyrgyzstan and China.

Table 1. SWOT analysis of the introduction of digital agricultural platforms between Kyrgyzstan and China

Category	Kyrgyzstan	China	Joint benefits
Strengths	Digital farming platforms can enhance productivity and market access	Strong technological expertise and infrastructure in agriculture	Collaborative agricultural innovation and joint research centres
Weaknesses	Limited digital infrastructure and financial constraints for smallholder farmers	Dependence on external markets and regulatory complexities in Kyrgyzstan	Cultural and organisational barriers to digital adoption
Opportunities	Increased export capacity and market access through digital platforms	Expansion of Belt and Road Initiative and increased agritech investments	Creation of regional data processing centres for efficient analysis
Threats	Resistance to technological change and policy misalignments	Cybersecurity risks and regulatory barriers to cross-border data exchange	Geopolitical risks and trade disruptions that could affect cooperation

Source: created by the authors

Despite these opportunities, the adoption of digital farming platforms in Kyrgyzstan faces several challenges. Limited digital infrastructure, financial constraints, and resistance to technological change among farmers are key barriers that must be addressed. Additionally, policy misalignments and high tariffs on digital components further hinder the widespread adoption of these technologies. However, with collaborative efforts, strategic investments, and policy reforms, these challenges can be overcome, paving the way for a mutually beneficial partnership.

For the successful implementation of digital farming platforms between Kyrgyzstan and China, a unified policy must be developed to facilitate the digital transformation of agriculture. A key component of this policy is the introduction of tax incentives for companies investing in the digitisation of the agricultural sector. Additionally, bilateral agreements regulating the exchange of agricultural data between the two countries are necessary to create a transparent and secure environment for cooperation. Reducing tariffs on digital equipment, sensors, and software will encourage faster adoption of advanced technologies, particularly among small and medium-sized enterprises, for whom initial investment costs remain a major barrier.

The development of digital and physical infrastructure is critically important for the effective use of digital farming platforms. Kyrgyzstan must prioritise the expansion of broadband networks in rural areas and implement 5G connectivity to support IoT devices and smart farming systems. A crucial aspect is the establishment of regional data processing centres, which will enable efficient analysis of information collected from digital platforms and provide rapid access to analytics for farmers and government institutions. The implementation of smart farming solutions based on IoT allows for resource optimisation and increased productivity. Sensors for monitoring soil conditions, nutrient levels, moisture, and temperature enable precise control over crop cultivation conditions. Automated management systems regulate irrigation, fertiliser application, and pest control, minimising resource use and improving the environmental sustainability of farming operations. AI-driven analytics can assist farmers in predicting yields, determining optimal planting schedules, and adopting sustainable farming practices tailored to local conditions (Morchid *et al.*, 2024).

Farmer training programmes are essential to ensure the successful adoption of digital farming platforms. Mobile applications with user-friendly interfaces should be developed to provide farmers with access to market prices, weather forecasts, and crop management tools. Collaboration with Chinese agritech firms can facilitate hands-on training sessions, while localised digital content in Kyrgyz and Russian can bridge language barriers. Increasing farmers' awareness of digital tools will accelerate the transition to data-driven agricultural management. Blockchain technology can revolutionise agricultural supply chains by ensuring traceability and transparency. Each step in the supply chain – from planting and harvesting to packaging and shipping – can be recorded on a blockchain, allowing buyers to verify the origin and quality of products (Kudrenko & Hall, 2024). Smart contracts can automate transactions, ensuring secure payments to farmers and reducing reliance on intermediaries. Blockchain systems can also enhance compliance with international trade standards, boosting the marketability of Kyrgyzstan's agricultural exports.

Collaboration between governments, tech companies, and farmer cooperatives is essential for the development and sustainability of digital farming platforms. Public-private partnerships can support the co-development of affordable IoT kits and farm management software tailored to Kyrgyzstan's needs. Additionally, establishing incubators for agritech start-ups can drive innovation and create localised solutions for agricultural challenges. Joint investment in digital agriculture will accelerate the adoption of new technologies and expand access to funding opportunities. Launching pilot projects in key agricultural regions such as Naryn and Chuy can demonstrate the tangible benefits of digital farming platforms. These projects should integrate IoT-based sensing technologies and automated irrigation systems to provide tangible benefits for farmers. The results of these studies can be used to showcase best practices and promote the scaling of digital agriculture across the country. Demonstrating real-world success through pilot programmes will increase farmer confidence in new technologies and encourage wider adoption.

Digital farming practices should be aligned with sustainability goals to promote resource-efficient farming models. AI tools can optimise water usage and energy consumption, while satellite imaging can assess land use and the extent of degradation. Encouraging precision farming through digital mapping systems can enhance the export potential of eco-friendly products. Sustainable agriculture initiatives must prioritise the long-term environmental impact of digital farming solutions to ensure that technology-driven advancements do not compromise natural ecosystems. Tailored financial instruments should be created to make digital solutions accessible to smallholder farmers. Micro-loans and subsidies should be provided for purchasing IoT devices and smart farming equipment. Shared ownership models, where cooperatives lease expensive machinery like drones and sensors, can also reduce costs for individual farmers. Financial support structures should aim to lower entry barriers and facilitate long-term digital adoption in rural agricultural communities (Nagaraja *et al.*, 2024).

Developing digital marketplaces that connect Kyrgyz farmers directly to Chinese buyers can streamline trade and reduce reliance on intermediaries. These platforms should integrate digital payment solutions, including mobile wallets and blockchain-enabled transactions, to simplify cross-border trade and improve farmer profitability. Transparent online trading platforms will help farmers secure better prices for their produce and expand access to international markets. Climate-smart agriculture solutions should be developed to help farmers adapt to changing weather conditions. Predictive analytics based on climate and weather data can enable farmers to take proactive measures against droughts, floods, and pest outbreaks. Early warning systems supported by satellite-based monitoring can further enhance resilience. These systems should be integrated into digital farming platforms to provide farmers with real-time recommendations on crop management and disaster preparedness.

By addressing these challenges and implementing the recommended technical solutions, Kyrgyzstan and China can unlock the full potential of digital farming platforms, driving agricultural productivity, economic growth, and environmental sustainability. The implementation of digital farming platforms is expected to significantly enhance the agricultural sectors of both Kyrgyzstan and China while fostering economic cooperation and technological advancements. For Kyrgyzstan, the integration of AI-driven analytics and precision irrigation systems will enable farmers to optimise resource usage, improve crop yields, and reduce environmental impact. Moreover, these platforms will contribute to economic empowerment by providing farmers with access to digital tools and market insights, allowing them to make informed decisions and increase their profitability. China, on the other hand, will benefit from expanding digital marketplaces that facilitate secure cross-border transactions through blockchain technology. This will not only strengthen China's influence in Central Asia but also open new avenues for investment in regional agritech start-ups. By leveraging its technological expertise, China can enhance its role in the global agricultural supply chain while supporting Kyrgyzstan in adopting innovative farming solutions.

The mutual advantages of digital farming extend beyond economic growth and trade expansion. Joint research centres focused on agricultural innovation and sustainable practices will drive scientific collaboration between the two countries. Additionally, the creation of harmonised regulatory frameworks will facilitate seamless agricultural data sharing and trade policies, ensuring transparency and efficiency in cross-border agricultural trade. These advancements will ultimately contribute to regional stability, increased food security, and long-term environmental sustainability. The detailed impacts of digital farming adoption are summarised in Table 2.

Table 2. Expected impact of digital farming platforms

Category	Impact	Additional benefits
For Kyrgyzstan	Implementation of AI-driven analytics for real-time crop health monitoring and pest detection	Integration of precision irrigation systems to optimise water use and reduce resource waste
For China	Expansion of digital marketplaces facilitating cross-border transactions with blockchain security	Investment in local agritech start-ups to enhance regional digital farming capabilities
Joint Benefits	Development of joint research centres for agricultural innovation and sustainable farming practices	Creation of harmonised regulatory frameworks to standardise agricultural data sharing and trade policies

Source: created by the authors

China and Kyrgyzstan can take the lead in agricultural innovation by adopting digital farming solutions and developing strategic alliances. If this project is successful, it will set an example for other nations looking to use technology to improve their agricultural industries. Overcoming any obstacles will require a well-coordinated strategy that incorporates infrastructural development, farmer education, and policy harmonisation. In the end, the broad use of digital farming platforms will strengthen China's and Kyrgyzstan's positions as leaders in resilient and intelligent agriculture while also increasing agricultural productivity and promoting sustainable economic growth.

▸ Discussion

Digitalisation of agriculture is a key factor in increasing productivity, optimising resources and developing agri-food systems. The use of digital platforms, the IoT, AI, and big data is transforming traditional agricultural production processes, contributing to efficient management, cost reduction, and improved logistics. However, the level of adoption of digital solutions in different countries and regions varies considerably, driven by both economic and socio-cultural factors. D.J. Choruma *et al.* (2024) studied agricultural digitalisation in Africa, focusing on smallholder access to technology and finance, and how IoT, AI, and Big Data can improve productivity and market integration. Both studies acknowledge the positive effects of digital technologies but highlight barriers like limited access to tech and finance. While D.J. Choruma *et al.* focus on smallholders, this study emphasises digitalisation's role in Kyrgyzstan's international trade and cooperation with China. Similarly, B. Ezeomah & R. Duncombe (2019) and this study both explore digital platforms in agriculture. B. Ezeomah & R. Duncombe focus on how digital platforms transform supply chains, while this study looks at state-to-state cooperation, international trade, and government agreements in driving digital agricultural transformation. B. Ezeomah & R. Duncombe explore various platform types, while this study focuses on public policy and economic impacts.

T. Qin *et al.* (2022) and this study both examine digital agriculture, focusing on IoT, big data, and AI to improve efficiency, resource management, and logistics. They highlight challenges like limited access to digital tools for small farmers and the need for supportive government policies. T. Qin *et al.* focus on macro-level digitalisation in China and the EU, while this study emphasises the practical use of digital platforms in specific regions and the role of public administration and international cooperation. Similarly, W. Gong *et al.* (2024) and this study explore digital agro-technological services and farmers' adoption of digital tools. Both stress the importance of digital literacy and transformation in agriculture. However, this study has a broader international focus, while W. Gong *et al.* focus on Sichuan Province, China. While they examine technology accessibility and economic motivation, this study looks at broader international digital integration in agriculture.

R. Zhong *et al.* (2022) explore digital technologies' impact on agriculture. R. Zhong *et al.* focused on the relationship between the digital economy, technological progress, and carbon reduction, while this study looks at how digital agriculture impacts ecosystem services and social well-being. Both agree on digitalisation's contribution to sustainable development, but R. Zhong *et al.* focus more on environmental performance, while this study addresses the alignment of digital agriculture with ecosystem needs and social well-being. The study by I. Taranov & Y. Kawabata (2024) and this research share a focus on improving agricultural efficiency in Kyrgyzstan, but differ in their approaches. Study by I. Taranov & Y. Kawabata emphasises organic farming and Participatory Guarantee Systems, focusing on local certification for smallholders. Both studies address challenges such as infrastructure limitations and the need for government support. However, work by I. Taranov & Y. Kawabata emphasises social aspects and local traditions, while this study focuses on the technological and policy dimensions of digital agriculture, including international cooperation and public administration.

Similarly, this study and G. Duginets & K. Nizheiko (2023) explore the role of digital technologies in agricultural development. Both highlight the importance of digital platforms, AI, and automation in improving productivity. However, while G. Duginets & K. Nizheiko focus on the European context and the environmental and regulatory aspects of digitalisation in Ukraine, this study takes a broader international perspective, examining digital transformation in global agricultural supply chains and cross-border cooperation. This study and the research by H. Chkarat *et al.* (2023) also share a focus on the role of digital platforms in agriculture, particularly for sustainable development and efficiency. Both studies recognise the importance of digitalisation for optimising resources and improving communication between farmers and government agencies. However, H. Chkarat *et al.* focused on the social, economic, and environmental prerequisites for deploying digital platforms, while this study investigates the practical implementation of digital solutions and their impact on supply chains, technology access for farmers, and agricultural productivity.

Digital platforms play a key role in the development of the agricultural sector, contributing to the optimisation of production, improved supply chain management and the use of big data, as confirmed by M. Kenney *et al.* (2020). This study also emphasises that digitalisation helps to reduce costs and increase farm efficiency. At the same time, M. Kenney *et al.* considered digital platforms as a global economic phenomenon, while this study focuses on local mechanisms for their implementation. Thus, both studies recognise the importance of digitalisation for the agricultural sector, but approach the analysis from different perspectives.

B. Wang & H. Dong (2023) examined farmers' behaviour towards digital agricultural services within a rural revitalisation strategy, highlighting the importance of technology adoption intentions, infrastructure availability, and factors like expected efficiency, social impact, and data quality. This study also explores digital agriculture but with a broader focus on economic efficiency and technology adaptation in agricultural production. Both studies recognise the role of infrastructure and farmers' intentions as key factors in digital adoption, but B. Wang & H. Dong concentrate on the behavioural aspects, whereas this study focuses on the strategic implementation of digital solutions in agriculture.

J.D. Borrero & J. Mariscal (2022) and this study both examine the role of digital platforms in improving production efficiency. J.D. Borrero & J. Mariscal focus on supporting farmers' decision-making through data management and platform transparency, while this study explores the integration of big data, machine learning, and cloud technologies in agriculture. The key distinction is that J.D. Borrero & J. Mariscal studied a specific digital platform for the fruit and vegetable sector, while this study addresses the broader digitalisation of agriculture. Both studies agree on the importance of effective platform management, but their implementation approaches differ.

A study by S. Brooks (2021) analysed the impact of digital platforms on the agricultural sector, emphasising their impact on farmer behaviour and the potential risks of dependence on financial structures. This study focuses on the practical implementation of digital technologies, their effectiveness in increasing productivity and sustainability of the agricultural sector. S. Brooks emphasised the risks of digitalisation, in particular deskilling and market actors' control over platforms, while this study considered digitalisation as a tool for optimisation. Both recognised the importance of digital technologies, but with different approaches – socio-economic in S. Brooks and technological-production in this study.

Study by K. Bronson (2019) explored the social and ethical challenges of digital agriculture, focusing on how digital platforms and big data are reshaping the agricultural sector, with large corporations gaining dominance and small farmers facing barriers. The study emphasised the growing technological inequality resulting from uneven digital benefits. This study also examines the digitalisation of agriculture but focuses more on its economic and technological aspects, specifically how digital platforms affect production efficiency and market performance. Unlike K. Bronson's work, this study addresses technological opportunities rather than social and ethical concerns.

M. Ayre *et al.* (2019) examined the role of advisors in the digital transformation of agriculture, while this study looks at broader trends in digitalisation. Both studies highlight the significance of digital tools in farm decision-making, but M. Ayre *et al.* emphasised the role of advisors collaborating with digital platforms, whereas this study focused on the impact of digitalisation on agricultural enterprise management. The main difference lies in M. Ayre *et al.*' s focus on the co-design of digital tools, while this study investigates structural changes in digital management.

The analysis shows that digital platforms play a key role in the transformation of agriculture, contributing to increased productivity, management efficiency, and integration of farms into global markets. At the same time, various studies point to barriers related to uneven access to technology, insufficient digital literacy, and economic constraints of small farmers. The use of digital solutions can improve the environmental sustainability of the agricultural sector, but requires coherent government strategies, international cooperation, and financial support.

▸ Conclusions

From 2001 to 2023, trade turnover between Kyrgyzstan and China has shown steady growth, indicating the strengthening of economic ties between the countries. Kyrgyz exports to China increased from USD 50 million in 2001 to USD 900 million in 2023, while imports from China increased to USD 3.6 billion, a significant share of which is machinery, electronics, textiles and construction materials. This indicates Kyrgyzstan's growing dependence on Chinese goods and the need to expand its own production capacity to reduce the trade deficit.

According to the results of the interviews, 70% of the farmers who participated said that they would be interested in adopting digital platforms, and 65% of them acknowledged the potential advantages of digital tools in terms of boosting productivity, expanding market access, and cutting expenses. Nonetheless, 85% of farmers identified major obstacles to adoption, such as low levels of digital literacy, expensive technology prices, and a lack of the required infrastructure. Experts in agriculture also underlined that although farmers were enthusiastic about digital technologies, government assistance was desperately needed.

The necessity of coordinating Kyrgyz and Chinese trade policy in the area of digital technology continues to be a major obstacle. Even while the amount of Chinese technology and digital solutions being imported is increasing, it is still necessary to standardise customs processes, control data sharing, and guarantee cybersecurity. State support in the form of funding digitalisation initiatives, offering financial aid for the acquisition of contemporary equipment, and putting in place training programmes to raise farmers' digital literacy are all essential for the prosperous growth of digital agriculture in Kyrgyzstan. In order to effectively deploy digital technology for crop forecasting, climate monitoring, and farm management, it is also critical to enhance infrastructure, particularly increasing access to high-speed Internet in rural regions.

This study is limited by the lack of long-term empirical data on the impact of digital technologies on the productivity of the Kyrgyz agricultural sector and its international trade. Further research could focus on assessing the effectiveness of the implementation of digital platforms in Kyrgyz agriculture, taking into account regional characteristics, the level of digital literacy of farmers, and the impact of government support.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Платформи цифрового фермерства як інструмент посилення співпраці між Киргизстаном та Китаєм: потенціал та перспективи

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► **Анотація.** Метою цього дослідження було оцінити роль цифрових сільськогосподарських платформ у зміцненні економічного співробітництва між Киргизстаном і Китаєм, зосередившись на їхньому потенціалі для підвищення продуктивності сільського господарства, оптимізації ресурсів і розширення доступу фермерів до ринків. Методологія дослідження включала аналіз первинних і вторинних джерел, проведення структурованих інтерв'ю з експертами, вивчення даних про торгівлю між Киргизстаном і Китаєм з 2001 по 2023 рік, а також оцінку бар'єрів і можливостей для цифровізації в аграрному секторі. Результати показали, що цифрові сільськогосподарські платформи сприяють покращенню логістики, підвищенню ефективності управління сільськогосподарськими процесами та сприяють міжнародному співробітництву. Експорт Киргизстану до Китаю збільшився з 50 млн у 2001 році до 900 млн доларів США у 2023 році, а імпорт досяг 3,6 млрд доларів США, що демонструє економічну взаємозалежність між двома країнами. Впровадження цифрових рішень, зокрема Інтернету речей, штучного інтелекту та блокчейну, мінімізувало витрати, уможливило прогнозування врожайності та вдосконалило ланцюги поставок. Результати дослідження показали, що цифровізація сільськогосподарського сектору Киргизстану має потенціал для значного підвищення його конкурентоспроможності та сприяння сталому економічному розвитку. Однак необхідно було вирішити низку проблем, зокрема фінансові обмеження, нерозвиненість цифрової інфраструктури та необхідність узгодження державної політики з цифровою економікою. Успішне впровадження цифрових рішень вимагає комплексного підходу, який охоплює як технологічну модернізацію, так і розвиток компетенцій фермерів для ефективного використання інноваційних інструментів

► **Ключові слова:** сільське господарство; впровадження технологій; ланцюжок поставок; блокчейн; продовольча безпека

Received: 18.07.2024. Revised: 23.12.2024. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.76

Ekonomika APK, 32(2), 76-86

UDC 631.151

Smart farming models in urbanised regions: Prospects for economic efficiency and sustainability

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► **Abstract.** The aim of this study was to assess the economic efficiency and sustainability of implementing smart technologies in agriculture within urbanised regions, specifically using the case of the agro-industrial holding "Myronivsky Hliboproduct" (MHP). The methodology incorporated both quantitative and qualitative analytical methods. An empirical analysis of the yield of key crops was conducted. To evaluate the economic efficiency of the implemented technologies, a graph of the company's income dynamics was constructed, enabling an assessment of the impact of smart technologies on the enterprise's financial performance. The key findings indicate that the adoption of smart technologies at MHP contributed to a significant increase in crop yields and a reduction in resource costs. For instance, maize yields rose from 8.6 t/ha in 2016/2017 to 10 t/ha in 2021/2022, remaining stable at 9.9 t/ha in 2023/2024. A similar trend was observed in other crops: rapeseed yields increased from 3.7 t/ha to 4.2 t/ha, while soybean yields grew from 2.4 t/ha to 2.8 t/ha. These results are attributed to the application of advanced techniques, including Real-Time Kinematic (RTK) navigation, automated management systems, and variable-rate fertilisation. An analysis of economic indicators revealed steady growth in the company's revenue even under challenging economic conditions. The graph demonstrated that MHP's income increased significantly during the period of active smart technology adoption. In 2024, the company's revenue reached USD 770 million, confirming

► **Suggested Citation**: Puyu, V., Ponichtera, P., Havryliuk, V., Sheiko, I., & Kozyrsky, D. (2025). Smart farming models in urbanised regions: Prospects for economic efficiency and sustainability. *Ekonomika APK*, 32(2), 76-86. doi: 10.32317/ekon.apk/2.2025.76.

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the economic efficiency of the implemented solutions. Furthermore, the use of digital platforms for field monitoring and process management optimised machinery maintenance costs and yield forecasting. The conclusions confirm that smart farming is an effective tool for modernising agriculture in urbanised regions. The practical significance of the study lies in demonstrating the efficiency of smart farming adoption for enhancing agricultural productivity. The results indicate the potential for substantial yield increases and resource cost reductions through the use of innovative technologies such as precision farming, digital platforms, and automation

▸ **Keywords:** innovative technologies; precision farming; digital platforms; process automation; yield dynamics

▸ Introduction

Urbanised regions face numerous challenges, including limited resources, high population density, and the need to ensure food security amid environmental instability. In this context, smart farming represents an innovative approach to agricultural production, integrating digital technologies, sustainable development strategies, and process automation. Such models enhance the productivity of agricultural systems, reduce ecological pressure, and optimise the use of constrained resources. Ukraine holds significant potential for the adoption of smart farming models, particularly in urbanised regions where industrialisation and urbanisation often limit access to land and natural resources. At the same time, innovative approaches to agricultural production are necessary due to global trends such as climate change, urbanisation, the need to reduce greenhouse gas emissions, and the adaptation to modern environmental responsibility requirements.

The agricultural sector in Ukraine faces challenges in adopting precision farming due to industry conservatism and farmers' limited awareness. O. Hrynevych *et al.* (2022) examined the impact of precision farming on the economics and efficiency of agricultural enterprises in Ukraine. Their study demonstrated that precision farming technologies can reduce costs, increase yields, and enhance resilience to environmental changes. However, the low adoption rate of these technologies is linked to limited resources and insufficient farmer awareness. Innovative methods play a crucial role in the development of smart technologies in Ukraine's agricultural sector, improving efficiency and competitiveness. A. Hutorov *et al.* (2021) explored the development of smart specialisation in Ukraine's agrarian sector, emphasising the importance of supporting rural entrepreneurship and establishing new technological platforms. They also highlighted the need for investment and infrastructure improvements to implement these strategies. The use of digital technologies in agriculture, including precision farming, process automation, and drone and satellite monitoring, was examined by O. Khaietska & I. Babiy (2024). They noted that the main barriers to adopting these innovations are high technology costs and inadequate infrastructure.

Agriculture faces challenges in implementing innovative technologies for sustainable development (Bekpayeva *et al.*, 2025). M. Gemtou *et al.* (2024) explored the use of smart technologies such as precision farming, water resource management, and energy efficiency. Their findings demonstrate the significant potential of these technologies to enhance productivity, optimise resource use, and reduce environmental impact. However, the authors highlight adoption barriers, including limited farmer awareness, insufficient funding, and lack of policy support. The digitalisation of agriculture in Ukraine is crucial for improving managerial efficiency. A. Tarasiuk & V. Hamalii (2021) emphasised the role of intelligent systems and machine learning technologies in enhancing agribusiness management but noted the absence of a comprehensive digital strategy.

E. Koutridi & O. Christopoulou (2023) investigated digital technologies in agribusinesses, analysing the implementation of Industry 4.0 technologies such as drones, the Internet of Things (IoT), and sensors. They found that these technologies hold great potential for increasing productivity, economic efficiency, and local adaptability. The growing urban population and associated food security challenges necessitate efficient resource use in urban agroecosystems. A.-S. Christmann *et al.* (2025) examined digital opportunities in smart urban agriculture, proposing a multi-level taxonomy encompassing digital technologies, data, and urban farming approaches. They also identified 20 organisational readiness factors for successful implementation. Their study demonstrated that integrating smart technologies can enhance economic, environmental, and social sustainability in urban agriculture. Climate instability and rapid urbanisation pose significant challenges to sustainable agricultural development in Africa. A.-L. Balogun *et al.* (2022) explored the potential of digitalisation for climate adaptation and sustainable agriculture, identifying opportunities for digital technologies to improve productivity, optimise resource use, and enhance farm management practices. However, the study also revealed infrastructure deficiencies, limited access to digital tools, and low digital literacy among farmers.

Overall, insufficient research has been conducted on the economic efficiency of precision farming, the influence of social factors on decision-making, and the adaptation of digital technologies to diverse agricultural policies and urban ecosystems. Further studies are required to assess their impact on regional economic stability and productivity enhancement under Ukrainian conditions. The objective of this study was to develop practical recommendations for the implementation of smart farming models in urbanised regions, aimed at enhancing economic efficiency and ensuring the sustainable development of agricultural production. The research tasks included analysing contemporary approaches to smart farming adoption in urbanised regions, considering resource availability and technological capabilities; and assessing the impact of smart technologies on economic performance and environmental sustainability in agricultural production within urbanised regions.

▸ Materials and methods

The study's timeframe spans from 2016 to 2024, enabling an analysis of dynamic changes and an evaluation of technology implementation effectiveness in the long term. Scientific sources dedicated to agricultural innovations, particularly precision farming, IoT, process automation, and digital platforms (Kumar *et al.,* 2024; Rane *et al.*, 2024; Sekhar *et al.*, 2024), were analysed. These sources facilitated a systematic approach to understanding the role of smart farming in improving productivity, reducing environmental impact, and ensuring sectoral resilience. The research focused on the agro-industrial holding "Myronivsky Hliboproduct" (MHP) due to its leadership in adopting modern precision farming technologies, process automation, and digitalisation. Empirical data included yield metrics for key crops (maize, wheat, sunflower, rapeseed, soybean), allowing an assessment of productivity dynamics relative to applied technologies. Data were sourced from publicly available reports detailing innovations, financial results, and production costs (Giua *et al.*, 2022). For economic evaluation, MHP's income statements (2016-2024) were used to construct a graph illustrating revenue trends alongside smart technology adoption (Naruzhna, 2023). External studies on Ukraine's agricultural sector, including smart technology adoption and market conditions, provided context for MHP's national and international positioning (Share UA Potential, 2018).

The methodology employed a mixed-methods approach, combining quantitative and qualitative analyses to evaluate smart technologies' impact on agricultural productivity and economic efficiency. This approach enabled a detailed examination of key innovation aspects, including yield fluctuations, financial outcomes, and enterprise stability. Primary methods included empirical analysis, featuring statistical evaluation of crop yield dynamics (2016-2024), to determine how precision farming, automation, and digital platforms influenced productivity. Longitudinal yield data were correlated with technology adoption timelines. Economic efficiency was assessed via financial analysis, with income trends visualised graphically. This highlighted revenue growth patterns, particularly during intensive innovation phases (e.g., Real-Time Kinematic (RTK) navigation, precision fertilisation, automated management systems). A systems approach ensured holistic understanding, integrating precision farming (resource optimisation), automation, and digital platforms (real-time monitoring/management). This method elucidated interconnections between innovation components, including resource efficiency and productivity gains.

▸ Results

Theoretical and practical foundations of smart farming. Precision farming, or smart agriculture, is a modern agricultural approach leveraging innovative technologies to enhance productivity, profitability, and environmental sustainability. It integrates digital technologies, automation, sensor systems, big data analytics, artificial intelligence (AI), and IoT, optimising all production stages – from soil preparation to harvest – through precise process management. Smart farming employs a field-specific approach, accounting for natural variations via remote sensing (satellite/aerial imagery, GIS) to monitor soil nutrients, moisture, temperature, and health. This reduces input costs, minimises fertiliser/water/pesticide use, and mitigates environmental harm. Sensor technologies are pivotal, enabling real-time plant/soil monitoring for rapid response. Robotics and automation are equally critical: modern tractors, drones, harvesters, and sprayers rely on pre-programmed algorithms for task precision (Kumar *et al.,* 2024). For instance, MHP extensively deploys drones for large-scale fertilisation and crop monitoring, significantly reducing labour/time costs. Its precision sprayers, coupled with drone surveillance, enable accurate problem detection and swift corrective measures. This approach enhances efficiency while reducing chemical usage, promoting ecological farming practices (MHP uses the…, 2018).

Machine learning and AI are also key components of smart farming. They are used to analyse large volumes of data, predict crop yields, and detect pests and plant diseases. For instance, AI-based platforms such as Climate FieldView can identify anomalies in plant development, such as nutrient deficiencies or early signs of disease. This enables farmers to implement precise measures in a timely manner, such as targeted fertiliser application or pesticide use only in specific areas of the field where needed. This reduces losses from uncontrolled pest or disease outbreaks while minimising treatment costs, thereby enhancing production efficiency. All components of smart farming can interact via the IoT, creating an integrated system. IoT devices such as drones, cameras, sensors, and automated systems facilitate data exchange, enabling automated decision-making. For example, an automated irrigation system initiates watering as soon as sensors detect insufficient soil moisture levels. The use of software and analytical platforms is a critical aspect of smart farming. These tools allow farmers to generate forecasts and analytics while managing all production processes from a single device. For instance, cloud-based platforms such as John Deere Operations Center or Climate FieldView enable the processing and storage of large datasets on crop yields, soil conditions, and meteorological data. This simplifies decision-making regarding resource optimisation, irrigation system adjustments, or fertiliser application, ultimately improving agricultural efficiency (Rane *et al.*, 2024).

At the same time, smart farming considers economic and social dimensions. The creation of new jobs in technology, improved education levels, and upskilling farmers all contribute to local community development (Borko & Jammal, 2024). Innovations also enhance food security by reducing reliance on imports. Although smart farming holds significant potential for sustainable agricultural development, its implementation faces several challenges. These include low technical literacy among farmers, high equipment costs, and limited infrastructure access in certain regions. Advances in technology, along with support from governments and international organisations such as the Food and Agriculture Organization of the United Nations, the World Bank, and the International Fund for Agricultural Development, create new opportunities for wider adoption of smart farming despite these barriers. Thus, smart farming is a multi-component system that

leverages modern technologies to enhance productivity, efficiency, and sustainability in agricultural production. When implemented, it generates new opportunities for the agricultural sector while promoting efficient resource use and supporting ecological balance.

Modern agricultural production is based on innovative cultivation methods such as precision farming, vertical farming, and AI applications. These technologies not only address the challenges of rising food demand but also promote efficient resource use, environmental sustainability, and increased profitability. Their integration into agricultural practice creates new production models that respond to contemporary challenges such as rapid urbanisation, limited land resources, and climate change. Precision farming is one of the most effective approaches, employing modern technologies to analyse and manage agricultural processes. The goal of precision farming is to use geographic information systems (GIS), satellite monitoring, and sensor technologies to study the natural conditions of each field plot in detail. This method optimises water, fertiliser, and other resource use while reducing costs and minimising environmental impact. For example, soil moisture sensors help determine the exact water requirements of crops, preventing over-irrigation, which often leads to water waste and soil erosion. The use of drones for field monitoring is another key aspect of precision farming. Drones can quickly identify problem areas, such as nutrient-deficient zones or pest infestations. They are particularly valuable for precision farming as they provide farmers with real-time data for decision-making. Moreover, drones are used to apply plant protection agents and fertilisers, significantly reducing labour time and costs (Sekhar *et al.*, 2024).

Vertical farming is another innovative approach that enables crop cultivation in urban environments. Vertical farms require less land, energy, and water, making them economically viable for urban entrepreneurs by optimising limited space and reducing resource expenditures, particularly water and energy, thereby lowering production costs. The core of this technology involves growing plants on multiple levels within climate-controlled facilities. Hydroponics, aeroponics, and other advanced techniques in vertical farming eliminate the need for pesticides and drastically reduce water and fertiliser consumption. For example, hydroponics reduces water usage by 90% compared to traditional farming – a critical advantage in water-scarce regions (Yarmolenko, 2023).

The ability to maintain stable production regardless of climatic conditions is a major advantage of vertical farming. Controlled environments maintain ideal temperature, humidity, and lighting to maximise plant growth. For instance, hydroponics, aeroponics, and spectrally tuned LED lighting enable precise control over growing conditions, ensuring optimal yields irrespective of external climate variability. This is particularly important as climate change disrupts traditional crop productivity. Vertical farming, which allows vegetables and greens to be grown directly in urban areas, has become a vital component of food security in highly urbanised countries such as Singapore.

The CropX system, which analyses real-time sensor data and provides irrigation and soil management recommendations, is a prime example of AI applications in agriculture. It offers customised irrigation advice, saving up to 50% of water while ensuring optimal moisture levels for crops and improving resource efficiency, thereby enhancing agricultural profitability. Farmers using this technology have achieved a 10% increase in yields and a 25% reduction in water consumption. AI is also used to analyse drone or satellite imagery, enabling rapid detection of issues such as pest infestations or nutrient deficiencies (Aggeek, 2021).

It is important to note that these innovative methods are often integrated with broader systems, such as farm management software, drone-based monitoring platforms, or data analytics tools, unlocking new opportunities for production optimisation. For example, integrating data from multiple sources (sensors, drones, GPS technologies) automates irrigation, fertilisation, and crop rotation planning, boosting productivity and reducing costs. Additionally, vertical farms can be equipped with AI-driven sensors and automated irrigation systems, creating fully autonomous farms with higher efficiency and minimal human intervention. In agriculture, successful implementation of innovative approaches depends not only on technology but also on workforce training, access to financing, and government support. Sustainable development of the agricultural sector requires farmer education in modern technologies, creating enabling conditions for adoption, and incentivising investments (Shahini *et al.*, 2023). Thus, the key innovative directions in agricultural production are precision farming, vertical farming, and AI integration. These approaches optimise resource use, increase yields, and mitigate environmental harm.

Population growth and limited land resources necessitate new methods of agricultural production, making smart farming increasingly popular in urban areas. This concept involves integrating new technologies into urban environments to ensure food security, optimise resource use, and reduce environmental impact. Smart farming creates new opportunities for the sustainable development of the agricultural sector in conditions where traditional farming methods face numerous challenges, such as land degradation, climate change, and rapid urbanisation (Makhazhanova *et al.*, 2024). By employing technologies such as precision irrigation, plant health monitoring systems, and data analytics for yield prediction, smart farming reduces water waste, prevents excessive use of chemical fertilisers and pesticides, and maximises the efficiency of limited land resources (Tanchyk *et al.*, 2024). This contributes to preserving soil fertility, mitigating negative impacts on ecosystems, adapting agriculture to climate change, and ensuring sustainable production in urbanised settings.

Urban areas typically have limited access to agricultural land, necessitating solutions that maximise the use of available space. For example, indoor farming projects are actively developing in Kyiv, such as Smart Oasis Farm, which collaborates with the National University of Life and Environmental Sciences of Ukraine to research vertical farming (Smart Oasis Farm…, 2020). In Mykolaiv, farmer Maksym Netudykhata created a unique “smart greenhouse” that autonomously controls irrigation, lighting, and heating, demonstrating the practical implementation

of smart technologies in agriculture (Agronews, 2025). In such contexts, smart farming involves vertical farming, enabling crop cultivation on multi-tiered structures. This significantly increases productivity per square metre while reducing the use of resources such as water and fertilisers.

Automation and digital technologies are key components of smart farming in urban environments. Solutions like CropX and Climate FieldView, developed using sensors and AI, enable real-time monitoring of all critical cultivation parameters. This includes tracking humidity, lighting, temperature, and CO_2 concentration, ensuring optimal plant growth conditions. For instance, AI-integrated automated irrigation systems conserve water by tailoring irrigation to plant needs. Such systems can save up to 50% of water through precise control and optimised scheduling. The use of these technologies can increase yields by 20-30% (8 best applications…, 2024), as plants receive the required amount of water at the optimal time, promoting stable growth and development (Van Gerrewey *et al.*, 2021).

Social aspects of smart farming are also important. These technologies create new employment opportunities, particularly in the development, maintenance, and implementation of digital solutions. Additionally, smart farming fosters educational initiatives, such as the Go2Agro project, which offers a "Farming from Scratch" course for veterans. Such programmes upskill workers, equipping them with the knowledge to launch agricultural businesses, which is crucial for enhancing the competitiveness of urban agro-systems (Basanets, 2024). This approach can make urban communities more self-sufficient in food supply, reducing dependence on foreign providers. Smart farming offers significant environmental benefits. It is more sustainable than traditional farming methods, such as intensive tillage, excessive use of chemical fertilisers and pesticides, and inefficient irrigation systems, as it reduces greenhouse gas emissions, conserves water, and minimises pesticide use (Oliynyk *et al.*, 2021). For example, urban vertical farms improve air quality and create green spaces, enhancing the urban microclimate (Share UA Potential, 2024). At its core, smart farming aligns with contemporary demands by providing an innovative agricultural approach tailored to urban regions. Its implementation promotes sustainable development, efficient resource use, increased productivity, and improved urban living conditions.

Economic efficiency of smart technologies. The agro-industrial holding MHP is one of Ukraine's leading agricultural enterprises, excelling in both innovative technology adoption and sustainable industry development (Ukrinform, 2018). The company not only employs modern production methods but also serves as a benchmark for the sector's progress in the country. MHP began implementing precision farming elements as early as 2012-2013, when this technology was just gaining traction in Ukraine. Since then, the company has consistently integrated cutting-edge solutions into agricultural production, prioritising efficiency and operational quality. Automated and parallel steering systems significantly reduced resource consumption, including fuel, fertilisers, seeds, and plant protection products, lowering production costs. Thanks to RTK navigation technology and high-precision positioning (with deviations of no more than 2.5 cm), substantial resource savings were achieved across large areas, optimising enterprise-wide processes.

The company rigorously tests new technologies under real-world conditions, including automated and parallel steering systems, precision farming (e.g., soil and weather monitoring sensors), advanced irrigation technologies, and analytical platforms for agricultural management. Testing involves field trials, comparative analysis across different plots, and monitoring changes in yield and resource expenditure. All technical solutions undergo stringent evaluation before large-scale implementation, ensuring efficacy and compatibility with Ukrainian agricultural practices. Additionally, MHP has developed digital field maps, a critical step for precise monitoring and analysis. Yield maps generated by automated systems enable accurate productivity assessments for each field, facilitating adjustments to production processes. Combined with regular soil agrochemical studies, this allows for optimised field management strategies. Since 2016, the company has developed its Digital AgroTech platform, serving as a mobile office for agronomists. It enables work planning, resource inventory management, field monitoring, and yield history analysis. In 2022, MHP also began implementing the Digital Agro 360 farm management system, integrating digital solutions for agricultural production management (Naruzhna, 2023).

Since 2017, MHP has significantly expanded the use of precision farming technologies, including the installation of automated steering systems and RTK navigation on tractors, the implementation of soil moisture and temperature sensors, and the increased deployment of drones for field imaging and crop condition analysis. This has enabled the company to cover over half a million hectares of land, substantially improving soil tillage accuracy and the optimisation of resources such as water and fertilisers. The company actively implemented a differential liquid fertiliser application system and equipped cultivators with control systems for applying aqueous ammonia as the primary nitrogen fertiliser. This has reduced fertiliser costs and increased application efficiency. Furthermore, MHP introduced variable-rate seeding technology and employed specialised fertiliser spreaders operating based on task maps for more precise and rational application of mineral and organic fertilisers. In 2018-2019, MHP expanded the use of weather monitoring and analysis systems, such as the AgLeader and WeatherSpy platforms, which became integral to field operations planning. In the context of climate change, these solutions enable agronomists to make more accurate decisions regarding sowing and crop management. Additionally, the company began actively testing drones for field monitoring, desiccation, and precision application of plant protection products. From 2022 onwards, MHP started utilising state-of-the-art equipment incorporating automation technologies for all key processes – from soil cultivation to harvesting. For instance, the company employs John Deere AMS functionality to automate technological processes. Technologies such as Augmenta for variable-rate fertiliser application ensure maximum precision and resource efficiency. During 2023-2024, MHP invested in modern machinery equipped with precision farming features. For example, precision seeders

with Precision Planting elements not only ensure uniform sowing but also simultaneously apply liquid fertilisers based on task maps. This approach avoids overseeding and significantly enhances efficiency (MHP uses the…, 2018). To assess the impact of precision farming technologies in the MHP agro-industrial holding, an analysis of the yield of key agricultural crops was conducted for the period from 2016 to 2024, when the active implementation of smart technologies began (Table 1). This analysis tracks productivity trends for crops such as maize, wheat, sunflower, rapeseed, and soybeans, demonstrating how innovative approaches contribute to yield improvement.

Table 1. Yield dynamics of key crops at MHP (2016-2024)

Season	Maize (t/ha)	Wheat (t/ha)	Sunflower (t/ha)	Rapeseed (t/ha)	Soybeans (t/ha)
2016/2017	8.6	6.5	3.2	3.4	2.4
2017/2018	7.3	6	3	3.3	2.1
2018/2019	6.8	5.9	3.1	3.4	1.6
2019/2020	9.4	6.4	3.6	3	2.7
2020/2021	5.6	5.1	2.8	2.6	2.3
2021/2022	10	5.9	3.2	3.3	2.5
2022/2023	7.2	5.5	2.5	3.8	2.4
2023/2024	9.9	6.6	3.1	3.7	3.2

Source: developed by the authors based on MHP (n.d.), Share UA Potential (2018), MHP uses the latest technology to spray its fields and controls the process with drones (2018)

The data from Table 1 indicate a significant impact of precision farming technologies on the productivity of agricultural crops at MHP between 2016 and 2024. The most evident positive changes are observed in maize yields, which peaked at 10 t/ha in the 2021/2022 season and remained consistently high in 2023/2024 (9.9 t/ha). This is attributed to the use of differential seeding, variable fertiliser application, and other advanced practices. Rapeseed also demonstrates steady productivity growth, reaching 3.7 t/ha in 2023/2024, confirming the effectiveness of precision seeding and timely fertilisation. Similar positive trends are observed in soybeans, which showed a gradual yield increase to 3.2 t/ha. This was made possible through innovations such as split fertiliser application, precision seeders with Precision Planting elements, and continuous soil monitoring. However, attention should be paid to the negative trends in the 2020/2021 season, when yields of all crops declined significantly due to extreme climatic conditions, including prolonged droughts, unexpected spring frosts, and abrupt temperature fluctuations during vegetation periods, which caused plant stress and reduced yield formation capacity. This underscores the need for additional investments in technologies that can adapt agricultural production to climate change.

A comparison between 2016 and 2024 demonstrates that the adoption of smart technologies has enabled MHP not only to maintain but also to significantly enhance the productivity of most crops, even under challenging conditions. This also proves that an integrated approach – combining modern machinery, digitalisation, and staff training – is key to improving agricultural efficiency. Thus, MHP serves as a successful example of innovation implementation in the agro-sector, ensuring economic resilience and competitiveness even in an unstable environment. The economic efficiency of innovative technologies in agriculture is determined not only by yield growth but also by financial indicators reflecting profitability, return on investment, and enterprise stability. For MHP, a leader in smart technology adoption, it is crucial to assess how these innovations have influenced its financial performance. To evaluate MHP's financial stability between 2016 and 2024, a graph of the company's revenue dynamics was constructed (Fig. 1).

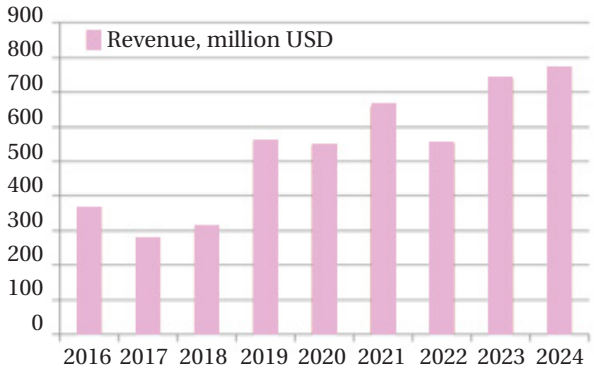

Figure 1. MHP's total revenue from 2016 to 2024
Source: MHP (n.d.)

The analysis of MHP's revenue dynamics indicates a positive impact of smart technologies on the company's financial efficiency. In 2016-2017, a slight revenue decline was observed, likely due to initial investments in new technologies. However, by 2018, revenues began to rise, and in 2019, a significant breakthrough was achieved – USD 560 million – reflecting the success of the implemented innovations. The highest results were recorded in 2023-2024, with revenues reaching USD 739 million and USD 770 million, respectively. These figures demonstrate that investments in precision farming, digital platforms, and modern equipment have paid off, enhancing competitiveness and financial stability. Thus, MHP exemplifies the successful integration of innovations to improve the economic efficiency of agribusiness. The MHP agro-industrial holding has demonstrated significant achievements in adopting smart technologies, which have improved crop productivity and the company's economic efficiency. The use of precision farming technologies – such as RTK navigation, automated control systems, and

soil monitoring sensors – has led to substantial reductions in resource costs (fuel, fertilisers, seeds, and plant protection products). Innovative methods, including differential fertilisation and precision seeding, have significantly increased resource efficiency, contributing to higher yields and lower production costs.

The analysis of yield dynamics from 2016 to 2024 confirms the positive impact of smart technologies on the productivity of key crops. Despite adverse factors, such as extreme weather in 2020/2021, MHP maintained and even improved yields through technological innovations and adaptation to changing conditions. The most notable increases were observed in maize, rapeseed, and soybeans, directly resulting from advanced agricultural technologies. Financial results also demonstrate that investments in precision farming and digital platforms have been profitable, ensuring revenue growth and financial stability. Rising revenues attest to the effectiveness of innovation adoption. For further development, MHP should continue investing in new technologies to adapt to climate change, such as automated irrigation systems, weather analysis tools, and expanded drone use for field monitoring. Additional digital platforms should be implemented for more efficient agri-management and integration with international systems to enhance competitiveness in foreign markets. To maximise the effectiveness of cutting-edge technologies, ongoing staff training and upskilling are essential to fully leverage the potential of smart farming.

▸ Discussion

The development of smart farming and its implementation in urbanised regions is a relevant topic in contemporary research. An analysis of scholarly work allows for a comparison of different authors' approaches to addressing efficiency, sustainability, and socio-economic impacts of innovative agricultural technologies. I. Richter *et al.* (2023) examined socio-economic barriers in African countries, such as Nigeria and South Africa, particularly the inaccessibility of technologies and adaptation challenges. Their study focuses on social aspects and technology localisation. In contrast, this research emphasises economic efficiency and environmental sustainability in urbanised regions of Ukraine, including technology integration in urban settings. P.-A. Langendahl (2021) analysed smart farming development in Sweden, highlighting socio-political aspects and ecological balance, stressing the importance of models such as "production as a service". The difference lies in that P.-A. Langendahl's work focuses on social and technopolitical dimensions, while this study prioritises economic and production aspects, such as resource efficiency and productivity gains.

G.N. Yuan *et al.* (2022) focused on a global overview of urban agriculture, particularly vertical farming, hydroponics, and aeroponics, addressing food security and ecological challenges. This study concentrates on technology adaptation in Ukraine, specifically economic efficiency and local conditions. Both studies highlight innovations, but G.N. Yuan *et al.* emphasise global aspects and policy barriers, while this research examines local implementations and financial support. S. Oh & C. Lu (2023) underscored technical aspects of vertical farming, such as hydroponics and IoT, and their benefits for food security. Their focus is on developed countries, whereas this study explores technology adaptation in Ukraine, including farmer training and local conditions.

A. Moghayedi *et al.* (2022) focus on the socio-economic aspects of smart farming, particularly the adoption of technologies in African countries. Their study places greater emphasis on the economic efficiency of smart farming in urban settings. R. Sasmitha *et al.* (2020) examine urban farming as a tool for sustainable development, specifically vertical farms and resource reuse. They devote more attention to social and environmental aspects, whereas this study focuses on the economic efficiency of technologies in the agricultural sector and the local conditions of Ukraine.

The study by L. Gurung *et al.* (2024) explores vertical farming as a promising method for sustainable urban agriculture, highlighting hydroponics, aeroponics, and aquaponics to reduce water consumption, pesticide use, and transportation costs. This aligns with the present study, which also emphasises innovation and environmental sustainability. Both approaches aim to address urbanisation challenges, such as resource scarcity, through the implementation of controlled environments. However, L. Gurung *et al.* place greater emphasis on global environmental impact and renewable energy use, whereas this study concentrates on local economic efficiency and the adaptation of smart technologies.

The study by F. Frimpong *et al.* (2023) explores vertical farming as a promising method for sustainable urban agriculture, highlighting hydroponics, aeroponics, and aquaponics to reduce water consumption, pesticide use, and transportation costs. This aligns with the present study, which also emphasises innovation and environmental sustainability. Both approaches aim to address urbanisation challenges, such as resource scarcity, through the implementation of controlled environments. However, F. Frimpong *et al.* are oriented towards water-saving practices for smallholder farms, including adaptation to regional conditions in West Africa, such as dry seasons and uneven rainfall distribution. This study, in contrast, is more focused on the economic efficiency of smart farming in urbanised regions, emphasising precision agriculture, automation, and digital technologies.

The study by M. Javaid *et al.* (2022) examines the implementation of Agriculture 4.0 technologies, such as IoT, AI, and blockchain, to optimise agricultural processes and reduce environmental impact. This aligns with the present study in the use of smart technologies for sustainable development. However, M. Javaid *et al.* emphasise a global perspective on digital farming, whereas this study focuses more on adapting technologies to local conditions in urbanised regions and economic efficiency. The study by S. Aciksoz *et al.* (2021) centres on smart urban farming to ensure food security and sustainable urban development, highlighting social benefits such as job creation. This aligns with the present study in the shared goal of sustainable development, but this study focuses more on the economic efficiency of smart technologies and local adaptation. Both studies underscore the importance of environmental aspects, but S. Aciksoz *et al.* emphasise the integration of farming into urban infrastructure, whereas

this study concentrates on the impact of innovations on agricultural productivity.

The study by G. Rajendiran & J. Rethnaraj (2023) focuses on integrating IoT and machine learning into vertical farming to enhance efficiency, reduce water consumption, and optimise resource use. This aligns with the present study in emphasising the adoption of innovations to address agricultural challenges and ensure food security. However, G. Rajendiran & J. Rethnaraj stress a global approach to vertical farming, whereas this study focuses more on local conditions in urbanised regions and the economic efficiency of technologies. The study by N. Khan *et al.* (2021) examines the integration of IoT, drones, and other technologies to optimise agricultural processes. This coincides with the present study in striving to enhance agricultural efficiency through smart technologies. Both approaches emphasise precision farming and data-driven decision-making. However, N. Khan *et al.* focus more on global perspectives and the development of new sensors, whereas this study highlights the adaptation of smart farming to urbanised regions and the use of existing technologies.

The study by M. Dhanaraju *et al.* (2022) explores the use of IoT in agriculture to optimise processes such as soil monitoring, water resource management, and yield prediction. Similar to the present study, it underscores the importance of modern technologies in improving efficiency and sustainability in agricultural production. Both studies emphasise the role of sensors and precision farming technologies in reducing resource costs and environmental impact. M. Dhanaraju *et al.* provide a detailed description of GPS, sensors, and software applications for real-time decision support. This study, however, is more focused on adapting smart farming to urbanised regions, whereas M. Dhanaraju *et al.* devote greater attention to the global application of IoT in addressing climate challenges and large-scale monitoring using drones. The study by N.M. Trendov *et al.* (2019) focuses on digital technologies, such as IoT, blockchain, and AI, for transforming agri-food systems. This aligns with the present study in using innovations to manage agricultural processes, but N.M. Trendov *et al.* cover a global scale, whereas this study concentrates on the local adaptation of smart farming in urbanised regions.

The present study demonstrates the integration of modern smart farming technologies in urbanised regions, emphasising their economic efficiency and adaptation to local conditions. A comparison with other studies reveals a shared objective – achieving sustainability and enhancing agricultural productivity through innovation. At the same time, differences lie in the context of technology application, socio-economic priorities, and the scale of analysis. This underscores the importance of a comprehensive approach to studying smart farming, considering both local and global aspects.

▸ Conclusions

This study confirms that the implementation of smart farming in urbanised regions is one of the key directions for the development of the modern agricultural sector. The integration of innovative technologies, such as precision agriculture, digital platforms, automation, and IoT, contributes significantly to increased productivity, resource-use efficiency, and agricultural sustainability. A notable example is the results achieved by the agroholding MHP, where the application of modern approaches has enabled consistently high yield indicators. Specifically, maize productivity increased from 8.6 t/ha in 2016/2017 to 10 t/ha in 2021/2022, remaining at 9.9 t/ha in 2023/2024. Such results were made possible through the use of RTK navigation, differential fertiliser application, and other innovations. A similar trend is observed for other crops. Rapeseed yields rose from 3.7 t/ha in 2016/2017 to 4.2 t/ha in 2023/2024, while soybean yields increased from 2.4 to 2.8 t/ha. This demonstrates the effectiveness of precision agriculture, which ensures rational use of fertilisers and water while adapting to climatic and soil conditions. Furthermore, the use of digital platforms for managing production processes helps reduce costs associated with equipment maintenance, field monitoring, and yield forecasting, thereby improving overall economic efficiency.

According to economic analysis, smart farming can significantly enhance profitability and reduce costs. High productivity levels under resource constraints demonstrate that modern technologies can ensure economic stability even in challenging conditions. Additionally, precision agriculture technologies reduce environmental impact by minimising pesticide, fertiliser, and water use. This not only improves economic indicators but also fosters long-term development by mitigating risks associated with external factors such as climate change and resource scarcity. Thus, the study proves that smart farming is a powerful tool for modernising the agricultural sector. It enables high economic efficiency, resource optimisation, and the creation of prerequisites for sustainable development in urbanised regions. Further progress in this direction requires a comprehensive approach, including technological innovation, workforce training, and financial support. Only through the combination of these factors can economic stability, agricultural resilience, and preparedness for future challenges be achieved.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Моделі смарт-фермерства в урбанізованих регіонах: перспективи економічної ефективності та стійкості

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► **Анотація.** Мета дослідження полягала у визначенні економічної ефективності та стійкості впровадження смарт-технологій у сільське господарство урбанізованих регіонів, зокрема на прикладі агроіндустріального холдингу «Миронівський хлібопродукт» (МХП). Методологія включала кількісні та якісні методи аналізу. Було проведено емпіричний аналіз врожайності основних культур. Для оцінки економічної ефективності впроваджених технологій побудовано графік динаміки доходів компанії, який дозволив оцінити вплив смарт-технологій на фінансові результати підприємства. Основні результати свідчать, що впровадження смарт-технологій у МХП сприяло суттєвому підвищенню врожайності та зниженню витрат на ресурси. Наприклад, урожайність кукурудзи зросла з 8,6 т/га у 2016/2017 році до 10 т/га у 2021/2022 році, а в 2023/2024 залишалася стабільною на рівні 9,9 т/га. Подібна динаміка спостерігалася у вирощуванні інших культур: урожайність ріпаку зросла з 3,7 т/га до 4,2 т/га, а сої – з 2,4 т/га до 2,8 т/га. Такі результати пояснюються використанням сучасних підходів, зокрема Real Time Kinematic навігації, автоматизованих систем управління та диференційованого внесення добрив. Аналіз економічних показників показав стабільне зростання доходів компанії навіть у складних економічних умовах. Графік продемонстрував, що доходи МХП значно зросли у період активного впровадження смарт-технологій. У 2024 році доходи компанії сягнули 770 доларів США, що підтверджує економічну ефективність застосованих рішень. Крім того, використання цифрових платформ для моніторингу полів і управління процесами дозволило оптимізувати витрати на обслуговування техніки та прогнозування врожайності. Висновки підтверджують, що смарт-фермерство є ефективним інструментом для модернізації сільського господарства в умовах урбанізованих регіонів. Практичне значення дослідження полягає у демонстрації ефективності впровадження смарт-фермерства для підвищення продуктивності сільськогосподарських підприємств. Результати свідчать про можливість значного зростання врожайності та зменшення витрат на ресурси через використання інноваційних технологій, таких як точне землеробство, цифрові платформи та автоматизація

► **Ключові слова:** інноваційні технології; точне землеробство; цифрові платформи; автоматизація процесів; динаміка врожайності

Received: 18.06.2024. Revised: 29.11.2024. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.87

Ekonomika APK, 32(2), 87-99

UDC 338.27:621.311.2(045)

Innovative financial instruments to stimulate the development of renewable energy

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► **Abstract.** This study examined contemporary financial mechanisms and instruments that facilitate investment in renewable energy sectors. The research methodology employed statistical analysis of electricity production and consumption data from renewable sources across the European Union and Ukraine. The findings demonstrated that the European Union has experienced substantial growth in renewable electricity generation, primarily attributable to effective investment attraction strategies. In contrast, Ukraine exhibits inconsistent development patterns in its renewable energy sector. The analysis underscored the correlation between robust financial frameworks and successful renewable energy adoption. While the European Union has implemented cohesive mechanisms yielding demonstrable results, Ukraine's renewable energy landscape reflects the consequences of less stable financial infrastructure. Total generation in the European Union increased from 750.9 thousand GWh in 2014 to 1,130.2 thousand GWh in 2023, which indicates a stable expansion of the sector. The most promising financial instruments were green bonds, which allow attracting significant capital investments for environmental projects, and energy cooperatives that contribute to the decentralisation of energy and the development of local communities. The mechanisms of financing renewable energy in the agricultural sector of European Union countries, in particular Germany, France, Poland, and the Netherlands, were analysed. The research examined the implementation of renewable energy within the agriculture sector, exemplified by RWE (Germany) and Astarta-Kyiv (Ukraine). It was shown that government subsidies, concessional lending, international investment, and corporate finance mechanisms played an important

► **Suggested Citation**: Reshetilov, G., Kuzoma, V., Bilichenko, O., & Tkachenko, M. (2025). Innovative financial instruments to stimulate the development of renewable energy. *Ekonomika APK*, 32(2), 87-99. doi: 10.32317/ekon.apk/2.2025.87.

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role in overcoming barriers. Ensuring sustainable financing of renewable energy in Ukraine requires an integrated approach, including active attraction of public, private, and international investment

▸ **Keywords:** alternative sources; environmental sustainability; investment mechanisms; government regulation; climate policy

▸ Introduction

The advancement of renewable energy technologies represents a critical component in addressing energy security concerns and mitigating climate change effects, particularly as global energy demands increase amidst finite conventional resource supplies. Solar, wind, hydroelectric, and bioenergy implementations serve not only to diminish fossil fuel dependence but also contribute significantly to agricultural sector development through bioenergy technology integration. Nevertheless, substantial financial impediments, including high capital expenditures and extended return-on-investment timeframes, necessitate the deployment of innovative financial instruments such as green bonds, specialised investment funds, and fiscal incentives to facilitate broader adoption. Research on these tools is important for raising capital and creating favourable conditions for the transition to a sustainable energy model.

Many researchers have considered various aspects of financing renewable energy and the possibility of using innovative financial instruments to stimulate it. X. Ye & E. Rasoulinezhad (2023) conducted a thorough analysis of the influence of green bonds on securing long-term investments in renewable energy. Their investigation focused on how the issuance of these bonds contributed to lowering the capital costs for renewable energy firms and enhancing investor trust. T. Kurbatova *et al.* (2021) examined the efficacy of governmental subsidies and tax incentives in Ukraine. V. Shebanina *et al.* (2024) examined approaches to the management of sustainable land use projects, considering the requirements of the European Union (EU), in particular, the need to attract innovative financial mechanisms, such as "green financing" and environmentally oriented investments. This highlights the importance of implementing comprehensive financial instruments to support the sustainable development of the agricultural sector, including renewable energy.

S.A. Sarkodie *et al.* (2020) examined the influence of foreign direct investment on the funding of renewable energy initiatives. Their analysis showed that in the presence of a stable political environment and transparent regulatory norms, international investors are ready to invest heavily in this sector. They also stressed that the lack of a clear government strategy and the risks associated with regulatory unpredictability may hinder the flow of foreign capital. L. Kostyrko *et al.* (2024) reviewed the public-private partnership (PPP) mechanism for financing renewable energy.

L.R. Vásquez-Ordóñez *et al.* (2023) explored the possibilities of raising funding through crowdfunding platforms. They proved that such platforms are an effective tool for financing small projects in the field of renewable energy sources, especially at the local level. Their research showed that the public actively supports clean energy projects if they have a transparent financial model and clearly defined environmental benefits. R. Yankovoy (2024) pointed to the role of venture capital in financing startups working on innovative technologies in the field of renewable energy. The researcher found that venture funds are willing to invest in high-risk projects if they have significant scaling potential and can deliver high returns in the future.

N. Fatima *et al.* (2021) examined the impact of companies' environmental ratings on their ability to attract funding for renewable energy projects. Their analysis showed that companies with high levels of environmental responsibility gain access to more favourable credit conditions and a wider range of investors. X. Zhang *et al.* (2022) devoted their research to the role of "green" banks specialising in financing environmental projects. They found that such financial institutions play a key role in stabilising investment flows in the renewable energy sector, as they minimise risks for investors and offer special credit products for sustainable development.

F. Egli (2020) reviewed risk insurance mechanisms for renewable energy investors. His research has confirmed that insurance products specifically designed for this industry significantly increase investor confidence and help to increase funding. The researcher further highlighted that insurance coverage accessibility for renewable energy initiatives contributes to capital cost reduction and enhances lending opportunities. O. Desyatnyuk *et al.* (2024) investigated digital technologies' impact on financial transparency within renewable energy sectors, demonstrating that blockchain implementation and smart contract integration can substantially enhance investment efficiency while minimising fraudulent activities and financial misconduct.

The introduction of green bonds, public-private partnerships, crowdfunding, venture financing, and other mechanisms creates new opportunities for attracting investment, which is critical for the sustainable growth of the industry (Khalegi *et al.*, 2024). However, there is a need for further analysis of their effectiveness and adaptation to modern economic and technological conditions. In particular, there is a lack of a comprehensive analysis of the effectiveness of various financial instruments in the long term, especially in conditions of macroeconomic instability. In addition, the issues of integrating digital technologies into financial mechanisms to increase their transparency and accessibility remain poorly researched.

This study aimed to assess the effectiveness of innovative financial mechanisms in catalysing renewable energy development and to identify potential enhancements in light of contemporary economic challenges. The research evaluated the influence of diverse financial instruments on renewable energy growth in both Ukraine and global contexts. It further examined the potential of digital technologies to enhance renewable energy

financing efficiency. Additionally, the study developed risk mitigation strategies specific to renewable energy investment. Through this comprehensive analysis, the research sought to inform policy and practice regarding optimal financial approaches to accelerate the renewable energy transition amid evolving economic conditions.

▸ Materials and methods

The research methodology was aimed at using secondary data from various sources, such as statistical reports, scientific publications, international reports and official data from national statistical authorities, which facilitated a comprehensive analysis of existing financial mechanisms and their impact on the development of renewable energy sources in Ukraine and EU countries. The main source for collecting information were Eurostat publications (2025a, 2025b) and research by international organisations such as the International Energy Agency (IEA) (n.d.) and the World Bank Group (n.d.). National programmes, including reports and documents on the implementation of energy reforms in Ukraine and international technical assistance programmes, were also used to analyse the financing mechanisms for renewable energy sources in Ukraine. Data regarding this matter was sourced from legitimate governmental entities, including the Ministry of Energy of Ukraine (n.d.). Prior resources have been utilised to examine financial processes including green bonds, energy cooperatives, crowdsourcing, and digital financial instruments.

The research methodology also encompassed a comparative examination of the indices of power generation from renewable sources in the European Union and Ukraine, with a specific focus on agriculture. For this purpose, data for the period from 2014 to 2023 from Eurostat publications (2025a, 2025b), and statistical reports of the national statistical agency of Ukraine, in particular, State Statistics Service of Ukraine (n.d.) were used. The comparative analysis allowed assessing the dynamics of renewable energy development in both regions and identifying key factors influencing the pace of its development. Restrictions: in Ukraine, there are no data for 2021-2023. This may be conditioned by economic difficulties, instability in the energy market, or military operations. To analyse the effectiveness of implementing renewable energy sources in the agricultural sector, several real-world cases of successful use of such technologies in different countries were selected. Particular emphasis was placed on examining the practices of prominent firms, such RWE (2024) in Germany and Astarta-Kyiv (n.d.) in Ukraine, which aggressively utilise biogas facilities and other renewable energy sources. Comparative analytic methodologies were employed to gather data on the adoption of renewable energy in the agricultural sector, facilitating the evaluation of project effectiveness exemplified by RWE and Astarta-Kyiv.

Furthermore, data about the application of digital financial solutions, including blockchain technology and smart contracts, utilised to enhance the transparency of financial transactions within the renewable energy sector was organised to evaluate financial processes. This helped to explore the potential of using digital financial instruments to reduce investment risks and increase confidence among agricultural market participants. The methods included qualitative and quantitative analysis, a comparative approach, and content analysis of scientific papers and reports of international organisations specialising in renewable energy sources. This facilitated the acquisition of information regarding the advancement of renewable energy across many regions. The methodologies employed in the study facilitated an exhaustive examination of renewable energy finance across the EU and Ukraine, specifically in the agriculture sector, and identified the most efficacious financing instruments for this business.

▸ Results

The modern world is rapidly moving towards energy transformation, where the main role is played by renewable energy sources. However, large-scale development of this industry is impossible without proper financial support. Conventional approaches to financing energy projects are often not effective enough, as renewable energy requires significant capital investment at the initial stage and has a long payback period. The most promising financial mechanisms include green bonds, energy cooperatives, crowdfunding, and digital financial solutions that combine state-of-the-art technologies and financial instruments to encourage environmental projects.

Green bonds are one of the most effective financial instruments for raising funds in the field of renewable energy (Rats & Alfimova, 2023). They operate on the principle of traditional bonds, but with the difference that the funds raised are directed exclusively to environmental projects. Government entities, private enterprises, and financial institutions issue these bonds to fund the development of solar, wind, and biofuel facilities. Their primary advantages include a decrease in capital costs attributable to state guarantees, enhanced investor confidence stemming from transparency in money utilisation, and the potential to secure foreign finance (Jain *et al.,* 2024). As of 2025, this tool is widespread in the EU countries, while in Ukraine it is just beginning to gain popularity.

Energy cooperatives are a form of collective financing that allows communities and individual consumers to invest in the creation of local renewable energy facilities. Members of the cooperative pool their resources to finance the construction of solar or wind power plants, and in return receive the benefit of cheaper or even free electricity. This mechanism contributes to the decentralisation of energy, reduces energy costs, and encourages local economic development (Gajdzik *et al.,* 2024). As of 2023, there were about 850 such cooperatives in Germany (Berg, 2023).

Crowdfunding is an innovative financial method that facilitates the acquisition of funds from numerous private investors via internet platforms. This approach is particularly effective for financing small projects that cannot receive traditional bank loans or government support. The main advantages of crowdfunding are the availability of financing for a wide range of investors, transparency and trust due to open online platforms, and the ability to quickly raise funds without bureaucratic procedures (Mukherjee *et al.*, 2024). In Western Europe, there are specialised platforms such as Solar Mosaic and Trine that

allow financing solar energy projects through contributions from individuals. In Ukraine, this mechanism, as of 2025, is not widely used, but it can become an effective tool for the development of local energy initiatives.

Modern digital financial solutions open up new opportunities for investing in renewable energy. Blockchain and smart contracts enhance the transparency of financial transactions and mitigate the risk of fraud. The use of decentralised financial platforms allows investors to interact directly with project developers without the participation of banks or other financial intermediaries (Razzaq *et al.,* 2023). These technologies ensure transaction transparency, automation of financial obligations, and global availability of investment opportunities.

The agricultural sector exhibits distinctive characteristics in renewable energy financing, primarily stemming from agricultural production's seasonal nature, autonomous energy requirements, and capital acquisition challenges faced by small and medium-sized farms. The implementation of renewable energy technologies in agricultural contexts offers dual benefits: reducing electricity expenditures while enhancing energy self-sufficiency for agricultural enterprises (Luchechko & Gordiichuk, 2023). Nevertheless, financial accessibility for such initiatives remains constrained, attributable to substantial initial investment requirements and insufficient collateral mechanisms to satisfy creditor demands.

Many countries around the world have programmes to support farmers who invest in solar panels, biogas plants, or wind turbines. For example, in the European Union, there are grant programmes under the Common Agricultural Policy (CAP), which provide for reimbursement of part of the cost of building renewable energy facilities (Gorokhova *et al.,* 2023). In Ukraine, there are separate state programmes to compensate for the cost of solar power plants for farmers, but their availability and efficiency remain limited due to insufficient funding and bureaucratic procedures.

An additional significant source of finance comprises international investment funds and loans from environmental financial institutions. The European Bank for Reconstruction and Development (EBRD) (n.d.) actively endorses initiatives concerning energy efficiency and renewable energy within the agriculture sector, offering loans at preferential interest rates. The World Bank Group and the Global Environment Facility (2023) offer co-financing programmes designed to mitigate greenhouse gas emissions by modernising agricultural infrastructure.

A separate niche in financing is occupied by energy cooperatives and corporate financing, which allow farmers to combine their resources for the construction of joint renewable energy plants. This model works well in Europe, where farmers' cooperatives receive financial support from local authorities and international investors. No less promising is the use of crowdfunding platforms and private financing, when farmers raise funds from citizens or private investors through specialised online platforms. This allows small farms to implement energy projects without having to take out expensive bank loans (Kragt *et al.,* 2021).

The advancement of renewable energy within the agricultural sector presents substantial prospects for small and medium-sized agricultural enterprises (SMAE), enabling them to not only decrease energy expenses but also to generate additional revenue from the sale of surplus electricity. Nonetheless, notwithstanding the economic advantages, securing money for the execution of such projects continues to be a challenging endeavour. The high cost of equipment, long-term payback and limited access to credit resources create serious financial barriers for farmers. Financing of SMAEs in the field of renewable energy is carried out through several main mechanisms. The traditional source is bank lending, but commercial banks are usually reluctant to lend to farmers due to the seasonal nature of agribusiness and high risks. In Ukraine, there is a programme of state lending, in particular, "Affordable loans 5-7-9%", which supports the agricultural sector, but its focus on renewable energy projects is limited (Ministry of Finance…, 2023).

One of the most effective mechanisms is equipment leasing, which allows SMAEs to install solar panels, biogas plants, or wind generators without the need for significant initial investment. For example, in Germany, more than 35% of agricultural enterprises use leasing to finance renewable energy, which significantly increases their level of energy independence (REN21, 2022). In addition to bank lending, government grants and subsidies play an important role. Other EU countries have the CAP programme, which includes funding for bioenergy projects in the agricultural sector (The common agricultural..., n.d.).

PPPs are an effective mechanism for attracting funding. This model allows agricultural enterprises to implement large-scale projects in cooperation with government agencies and private investors. For example, Denmark has implemented the Green Farm Energy programme, under which the government co-finances projects for the construction of biogas plants on farms, which significantly reduces the financial burden on farmers. New opportunities are being opened up by digital financial platforms that allow raising funds directly from the public. In the Netherlands, there is a model of energy cooperatives, in which farmers combine resources to jointly invest in wind and solar power plants (Technopolis, 2023).

Thus, the specifics of financing renewable energy in the agricultural sector are determined by a number of challenges, including high initial costs, the need for state support, difficulties in attracting loans for small businesses, and the seasonal nature of farm incomes. Successful development of this area is possible only if various financial mechanisms are actively involved, in particular green bonds, energy cooperatives, crowdfunding, government grants, and digital financial solutions (Rijanto, 2021). Considering the significant potential of renewable energy in agriculture, it is essential to design innovative finance solutions to promote investment and expedite the energy transition in rural areas. The European Union occupies a prominent role in renewable energy, executing extensive programmes to diminish reliance on fossil fuels and lower greenhouse gas emissions. Table 1 presents the generation of power from renewable sources.

Table 1. Volume of electricity production from renewable sources in the EU and Ukraine for 2014-2023, thous. GWh

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU	750.9	762.2	775.4	778.7	838.0	869.9	954.6	960.3	978.9	1,130.2
Austria	53.3	49.8	52.4	53.9	52.3	56.7	57.5	56.0	54.7	62.8
Belgium	10.1	11.1	11.1	12.4	13.8	16.1	20.3	19.9	22.3	26.2
Bulgaria	8.3	9.5	8.1	7.1	8.4	6.6	6.8	8.2	7.5	8.3
Greece	12.2	14.7	14.7	13.6	15.9	15.8	17.3	21.8	22.2	24.2
Denmark	13.7	14.8	13.5	15.5	14.9	17.1	17.5	17.4	21.2	22.8
Spain	112.5	97.8	105.9	87.3	102.9	99.9	114.6	125.2	125.1	150.1
Italy	105.4	92.4	92.2	88.2	98.7	100.0	101.2	101.4	86.6	103.7
Netherlands	6.6	8.8	9.9	12.8	14.3	17.0	23.9	29.5	38.3	49.2
Germany	126.0	150.3	149.9	177.4	183.6	202.1	213.7	195.2	215.6	235.1
Norway	139.1	142.1	146.1	146.7	144.3	132.3	153.1	156.7	145.5	-
Poland	11.0	14.0	15.8	18.6	15.9	19.2	21.5	24.0	32.2	40.3
Portugal	30.2	23.5	31.6	22.8	28.7	26.9	29.4	30.6	28.1	36.2
Finland	14.5	19.1	18.9	19.6	19.2	18.6	24.4	24.6	25.9	31.0
France	100.0	95.7	101.6	95.6	116.4	114.4	126.1	121.8	115.8	138.9
Czech Republic	6.6	7.2	7.0	7.0	6.7	7.4	7.7	7.7	7.3	8.1
Sweden	75.3	92.0	77.9	83.0	79.3	85.9	101.1	102.7	105.3	103.7
Ukraine	11.7	10.1	12.4	13.8	15.9	14.2	16.8	-	-	-

Source: compiled by the authors based on Eurostat (2025a) and State Statistics Service of Ukraine (n.d.)

Total generation in the EU increased from 750.9 thousand GWh in 2014 to 1,130.2 thousand GWh in 2023, which indicates a stable expansion of the sector. Germany shows a particularly significant increase (from 126 to 235.1 thousand GWh), the Netherlands (from 6.6 to 49.2 thousand GWh), Poland (from 11 to 40.3 thousand GWh) and Spain (from 112.5 to 150.1 thousand GWh). In some countries, such as Bulgaria and the Czech Republic, indicators remain almost unchanged, which may indicate insufficient state support or technical restrictions. The figures generally demonstrate the vigorous advancement of renewable energy across most European nations, however, the growth rate is inconsistent. The results reveal erratic trends in the advancement of renewable energy in Ukraine. Since 2014, generation volumes have ranged from 10.1-16.8 thousand GWh, which is significantly less compared to other European countries.

The EU's policy seeks to attain climate neutrality by 2050, necessitating substantial investment in renewable energy sources. The agricultural sector is essential in this setting, serving as both a major energy consumer and a potential energy producer through biogas plants, solar panels, wind turbines, and other technologies (Perissi & Jones, 2022). Table 2 shows the consumption of electricity from renewable sources by agriculture. Such projects are financed through a multi-level support system that includes government grants, loans, tax incentives, mechanisms for attracting private investment, and digital financial solutions. Based on these tools, farmers and agricultural enterprises can obtain financial resources to implement environmentally friendly technologies that not only reduce energy costs, but also create additional sources of income.

In general, the indicators show growth until 2021, after which there is a slight decline. Total consumption in the EU increased from 27.5 thousand GWh in 2014 to a peak of 38.8 thousand GWh in 2021, after which it decreased to 36.1 thousand GWh in 2023. This may be conditioned by changes in the production structure, increased energy efficiency, or economic factors. The highest rates are traditionally shown in Germany, where consumption increased from 7.1 to 9.4 thousand GWh, which reflects the active development of agricultural renewable energy. A significant increase in consumption is observed in France (from 1.9 to 5.0 thousand GWh) and the Netherlands (from 1.8 to 4.7 thousand GWh in 2021, with a further decline). However, in some countries, such as Poland and Finland, after a period of growth, there was a decline in indicators, which may suggest a change in energy policy or optimisation of consumption. The overall trend indicates a gradual increase in the role of renewable energy in EU agriculture, although in some countries, the dynamics are unstable. As for Ukraine, from 2014 to 2020, a gradual increase in the use of renewable electricity in the agricultural sector was recorded – from 173.1 GWh in 2014 to 321.7 GWh in 2020.

Table 2. Volume of electricity consumption from renewable sources by agriculture in the EU and Ukraine in 2014-2023, GWh

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU	27,535.9	29,415.4	32,173.0	33,710.1	34,762.5	35,377.9	36,487.8	38,797.8	37,847.4	36,064.6
Austria	2,050.1	2,102.2	2,140.6	2,224.7	2,023.3	1,884.2	1,831.2	2,149.8	2,033.7	1,985.0
Belgium	542.4	578.6	555.8	513.5	492.8	460.6	489.8	407.5	397.4	344.3
Bulgaria	80.0	130.6	205.8	90.3	57.1	56.2	65.8	119.4	115.0	128.3
Greece	346.4	363.3	360.3	349.4	370.1	379.0	328.4	314.6	348.2	366.4

Table 2, Continued

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Denmark	621.8	632.9	641.9	632.0	634.6	628.1	610.5	660.2	638.0	638.5
Spain	873.6	833.3	801.0	810.0	830.0	831.1	829.5	828.9	856.0	833.5
Italy	433.3	583.6	587.8	591.0	580.0	619.1	611.9	880.7	864.8	795.4
Netherlands	1,783.6	2,220.8	2,372.2	2,637.8	3,241.3	4,008.0	4,418.4	4,718.8	4,631.0	3,548.9
Germany	7,078.2	7,644.1	8,092.2	8,451.0	8,879.3	8,940.0	9,510.4	9,702.4	9,619.1	9,374.4
Norway	0.9	0.5	1.0	1.4	1.0	2.8	1.9	5.8	0.9	1.7
Poland	5,455.0	5,733.6	6,064.2	6,020.0	5,859.2	5,549.2	5,677.3	6,732.6	5,500.7	5,083.8
Portugal	56.4	51.7	37.2	31.0	55.0	63.5	64.9	70.7	33.3	35.0
Finland	2,009.1	1,805.1	2,011.6	1,942.2	1,894.9	1,868.3	1,680.8	1,983.6	1,893.2	1,939.0
France	1,884.7	1,994.2	2,947.0	3,589.1	4,137.8	4,162.7	4,482.9	4,533.3	4,506.0	4,968.3
Czech Republic	1,413.3	1,436.4	1,707.5	1,626.4	1,560.6	1,550.8	1,575.0	1,782.7	1,781.9	1,764.3
Sweden	1,727.6	1,778.7	2,048.7	2,404.6	2,393.9	2,605.1	2,542.8	2,319.3	2,951.3	2,545.4
Ukraine	173.1	225.0	229.2	295.3	427.2	321.1	321.7	-	-	-

Source: compiled by the authors based on Eurostat (2025b) and State Statistics Service of Ukraine (n.d.)

One of the key sources of financing for renewable energy is European support programmes and funds, among which the Horizon Europe programme occupies a special place. It is aimed at financing research and innovation projects in the field of clean energy, in particular, supporting farms in the introduction of biogas plants, solar panels, energy storage systems, and energy saving technologies. Horizon Europe provides funds for projects that facilitate the transition to sustainable energy. The European Green Deal significantly influences finance, shaping the strategic trajectory of the EU's environmental reform efforts. This initiative funds programmes to adapt agriculture to climate change, introduce low-carbon technologies, and support farmers who invest in clean energy (Onabowale, 2025).

In addition to grant financing, EU countries actively use lending mechanisms through the European Investment Bank (EIB), which provides soft loans for the construction of solar and wind power plants in the agricultural sector. The EIB supports projects on biomethane production, modernisation of agricultural infrastructure and introduction of energy-efficient technologies. In addition, the European Strategic Investment Fund (EFSI) plays an important role, which helps to attract additional private financing for the development of renewable energy. An important component of financing is also the activities of national development banks, such as the Credit Institute for Reconstruction in Germany, Deposits and Consignments Fund in France and Deposits and Loans Fund in Italy, which provide special loans to farmers for the introduction of green technologies (Bourgeois *et al.*, 2022).

One of the most common types of renewable energy sources in the European agricultural sector is biogas plants, which allow processing agricultural waste, manure, silage, and food residues into biogas used to generate electricity, heat, or biomethane. The French government aims to elevate the proportion of renewable gases in natural gas consumption to 10% by 2030. The long-term energy plan (PPE) stipulates the injection of biomethane ranging from 14 to 22 TWh by 2028. As of the end of 2022, there were 1,705 biogas plants operating in France, of which 514 processed it into biomethane for injection into the grid. This indicates significant progress in the development of biogas technologies in the country (Bioenergy Association of Ukraine, 2024). Poland actively supports the introduction of biogas technologies in agriculture. In September 2024, the European Commission approved a EUR 1.2 billion state aid scheme for Poland to support investments in strategic sectors, including renewable energy. This scheme aims to promote the transition to a zero-net-emission economy and support projects related to biogas plants (Commission approves..., 2024).

The use of photovoltaic panels on farm roofs and farmland reduces energy costs and makes a profit from selling excess electricity to the general grid. The Netherlands is actively developing this area through the SDE++ (n.d.) programme, which provides subsidies for the installation of solar panels and guarantees farmers favourable tariffs. Due to this programme, more than 500 solar projects have been implemented in farmers' cooperatives. Solar power in Germany is experiencing a significant upswing. In 2023, about 14 gigawatts of new photovoltaic capacity were put into operation, which is equivalent to the capacity of 12-14 nuclear power units. This is an 85% increase compared to 2022. About 31% of the increase was provided by new large solar power plants built by energy companies in the fields and along autobahns. Approximately 18% of the new capacity was installed on the roofs of commercial buildings, such as factories, warehouses, and agricultural structures (Hurkov, 2024). In Germany, through the Renewable Energy Programme (Credit Institute for Reconstruction Development Bank, n.d.), agricultural producers can receive soft loans at 1.5% per annum for the installation of photovoltaic systems, and grants covering up to 40% of the cost of installing solar power plants with a capacity of up to 100 kW. France also actively supports farm solar initiatives through the The Solar Plan (n.d.) programme, within which EUR 300 million is allocated annually for subsidies for farmers who invest in photovoltaic installations.

The development of renewable energy in Ukraine has gained significant momentum as the nation pursues energy independence, economic decarbonisation, and sustainable investment attraction. Within the context of the global environmental crisis and escalating conventional energy prices, renewable energy utilisation has emerged as an area of strategic importance. Financial mechanisms warrant particular attention, as without effective funding structures, green energy implementation in Ukraine risks

remaining confined to localised initiatives without achieving the transformative impact necessary for the national energy infrastructure. E. Shahini *et al.* (2024) analysed the prospects for the development of renewable energy in Ukraine in the context of energy crises and military operations, focusing on the need to introduce new financial mechanisms to encourage investment in this area.

The Ukrainian renewable energy market is developing unevenly. Until 2020, a significant role in stimulating the industry was played by the "green tariff", which provided attractive conditions for investors. However, over time, political and economic instability, and debts to renewable energy producers, slowed down the growth dynamics. The government was forced to renegotiate the terms of support for the industry, which led to a decrease in investor interest and the search for alternative financial mechanisms (Voloshyna-Sidei *et al.,* 2023).

The attraction of investment capital into renewable energy projects in Ukraine presents significant potential through green bonds. This financial instrument facilitates capital mobilisation for environmentally sustainable initiatives, particularly the development of solar and wind power infrastructure. However, it is noteworthy that the green bond market in Ukraine remains in its nascent stages, necessitating both governmental support mechanisms and enhanced investor confidence to achieve maturity. The agricultural sector represents a critical domain for renewable energy financing in Ukraine. The country possesses considerable bioenergy development potential, given the substantial organic waste generation within its agricultural operations-materials suitable for conversion to biogas and bioethanol. Nevertheless, the financing of such initiatives encounters persistent obstacles, primarily attributable to the capital-intensive nature of necessary equipment and insufficient availability of tailored credit programmes. Agricultural producers typically face prohibitive constraints in self-financing biogas facilities or photovoltaic installations due to extended amortisation periods, which presents a significant barrier to adoption.

Addressing this issue necessitates the engagement of international financial organisations, specifically the European Bank for Reconstruction and Development, the World Bank, and other entities that actively endorse energy reforms in Ukraine. In addition, it is promising to introduce energy cooperatives that allow combining the financial resources of agricultural producers for joint production and consumption of green energy. Successful examples of such initiatives exist in Europe as of 2025, and their adaptation in Ukrainian conditions can contribute to a faster transition of the agricultural sector to renewable energy.

The integration of renewable energy into the agricultural sector is a crucial aspect of contemporary advancements in sustainable and eco-friendly technology in agriculture. This diminishes reliance on traditional energy sources, mitigates greenhouse gas emissions, and offers economic advantages for farmers. The European Union and Ukraine have executed several successful instances of renewable energy utilisation in agriculture, employing various financial models and methodologies.

RWE (2024) is one of the largest energy companies in Germany and is active in the field of renewable energy sources, in particular biogas, through its RWE Bioenergy project. This project focuses on generating energy from biogas obtained by processing organic waste such as manure, straw and crop residues produced on farms. In addition to reducing the burden on conventional energy sources, the project helps farms reduce energy costs and simultaneously improve their financial results.

One of the key areas of RWE's work is the integration of biogas plants in agricultural enterprises, which allows optimising energy consumption in rural areas. One such project, located in southern Germany, consists of several biogas plants that run on organic agricultural waste. The system uses materials produced during the agricultural cycle, such as manure, organic residues from grain processing, and straw. Due to this process, RWE biogas plants are capable of generating up to 50 MW of electrical energy. This allows meeting the energy needs of not only farmers themselves, but also surrounding rural communities, which helps to reduce dependence on external energy suppliers. In addition, the electrical energy coming from biogas plants is used to heat agricultural buildings and other facilities on farms.

The RWE Bioenergy project also contributes to the development of the local economy, as the construction and operation of biogas plants creates new jobs, both at the stage of project implementation and at the stage of their operation. Farmers and other local residents have the opportunity to get involved in such enterprises, which contributes to the development of rural areas and reduces the unemployment rate in the regions. Through the use of biogas for energy production, farmers can not only reduce energy costs, but also integrate modern technologies into their production processes. This is an important part of Germany's strategy to move towards sustainable agriculture, which actively uses renewable energy sources.

Astarta-Kyiv (n.d.) is among the major agricultural enterprises in Ukraine, specialising in the cultivation of cereals, oilseeds, and the production of sugar and various agricultural products. The corporation actively integrates advances in the energy industry, particularly through the utilisation of renewable energy sources, alongside traditional fields. These programmes seek to diminish reliance on traditional energy sources, enhance energy efficiency, and minimise the environmental impact. Astarta-Kyiv's primary focus on renewable energy is bioenergy. The corporation is actively establishing biogas facilities to convert organic waste from agricultural produce into electricity.

The company's bioenergy project provides for the creation and operation of biogas plants at its agricultural enterprises. One of these stations operates at the production facilities of Astarta in the Poltava Oblast. This station processes organic waste generated during the production of agricultural products, in particular, after processing grain and other products. The capacity of this plant allows generating up to 5 MW of electric and thermal energy for the needs of the enterprise. The installed capacity of the plant allows generating electric and thermal energy for the company's needs, which significantly reduces energy supply costs.

The implementation of the company's bioenergy projects also has a positive impact on local communities, in particular, on the economic development of rural regions. Since biogas plants require organic raw materials to operate, this provides an opportunity for cooperation with

local farms, which provides additional income for rural residents. In addition, bioenergy projects allow creating new jobs, which is important for the development of the rural economy. V. Havrysh *et al.* (2023) note that the development of bioenergy projects based on agricultural revenues requires the introduction of financial incentives, such as soft loans and "green tariffs", to attract investment and minimise risks for investors.

Successful deployment of renewable energy sources in agriculture necessitates consideration of financial risks stemming from substantial initial investments, technological uncertainty, and potential volatility in the energy market. To minimise these risks, it is necessary to carefully assess the financial stability and technical reliability of projects at the planning stage. Investors should not only count on the economic benefits of implementing such projects, but also consider the potential risks associated with possible changes in technology or market prices for energy.

Utilising public-private partnership arrangements is one of the most successful strategies for mitigating financial risks, since it facilitates the distribution of risks between public and private investors. Attracting state support in the form of subsidies, concessional loans or tax incentives provides investors with additional guarantees, which significantly reduces the impact of high initial costs and long payback periods for projects. This approach creates conditions for balancing the interests of all participants, which ensures efficient use of resources and stable development of the sector.

To further reduce risks, attention should be paid to the introduction of insurance mechanisms that help to protect investments from unexpected circumstances, such as natural disasters or changes in legislation. Insurance of investments or the use of special financial products for renewable energy sources will help to reduce financial risks and attract additional funds for the implementation of such projects. In addition, it is important to diversify sources of financing, in particular, by attracting international funds that actively support initiatives in the field of clean energy.

The last but not least step is to constantly monitor and adapt projects to changing market conditions and technologies. As the renewable energy industry is changing rapidly, it is important to have mechanisms in place to continuously analyse and adjust financial and technological strategies in line with new trends. This approach will ensure the stability and sustainable development of renewable energy projects, reducing financial risks, and maximising their efficiency.

▸ Discussion

The financing of renewable energy projects in Ukraine, especially within the agricultural sector, is essential for attaining energy independence and sustainable development. The study's findings indicate that several viable finance mechanisms are now employed in Europe, and their adoption in Ukraine could facilitate the robust advancement of renewable energy. Specifically, instruments like green bonds, energy cooperatives, crowdsourcing, and digital financial solutions can markedly diminish financial obstacles and promote investment in renewable energy sources.

A highly promising mechanism is the utilisation of green bonds. These instruments facilitate the attraction of investment to fund ecologically sustainable initiatives, namely for the development of solar, wind, and bioenergy facilities. The European experience demonstrates that green bonds not only lower capital costs through governmental guarantees but also facilitate the acquisition of international funding (Kubiczek, 2020). In Ukraine, this mechanism is just beginning to gain popularity, and its development requires the creation of favourable conditions both at the level of state policy and in the context of building confidence among investors. L. Zhao *et al.* (2022) also focused on the analysis of financing mechanisms for renewable projects through green bonds, noting that in Europe, this tool allows attracting significant investment in solar, wind, and bioenergy, reducing the cost of capital through state guarantees and opening up access to international financing.

O. Dovgal *et al.* (2024) notes that the circular economy can be effectively combined with innovative financial instruments that promote the development of renewable energy even in crisis conditions, providing comprehensive support for "green" investments. U.S. Bhutta *et al.* (2022), in turn, suggest that for its effective development, it is necessary to create favourable conditions at the level of public policy and ensure confidence among investors. This coincides with the results of the current study, which also highlighted the importance of green bonds for attracting investment in renewable energy sources, although it was noted that for their widespread implementation, several barriers, including legal and economic ones, need to be overcome.

Another important area is energy cooperatives, which allow communities and individual consumers to pool resources to finance renewable energy sources. In Ukraine, this mechanism is just beginning to develop, but it has great potential in rural areas, where the issue of energy independence is extremely important. The development of cooperatives can be an important step in decentralising energy and reducing electricity costs for the rural population. J. Jasiński *et al.* (2021) investigated the role of energy cooperatives in the development of renewable energy, in particular, on the example of rural communities. The researchers argued that energy cooperatives are an important tool for decentralising the energy system, allowing communities to create their own energy sources and reduce energy costs. T. Bauwens *et al.* (2020) suggest that such cooperatives can become particularly effective in rural areas, where access to centralised energy resources is limited and energy independence is of great importance. This approach can reduce electricity costs for the rural population, although there is a need to improve the legal framework and the existence of investment barriers.

Crowdfunding is another promising tool for attracting financing for renewable energy projects, in particular, for small projects that cannot receive traditional bank lending. The transparency of crowdfunding platforms, the speed of fundraising, and involvement of a wide range of investors make this mechanism particularly attractive for projects in the renewable energy sector. In Western Europe, there are specialised platforms for financing solar projects, and this experience can be adapted in Ukraine. I. Appiah-Otoo *et al.* (2022) investigated the use of

crowdfunding to raise funds for small renewable energy projects, in particular, for solar and bioenergy installations, which allows small agricultural enterprises and citizens to implement energy projects without having access to conventional financing. The researchers emphasised the speed of fundraising through crowdfunding platforms, and the broad involvement of investors from different regions. This coincides with current findings, which also identified crowdfunding as an important tool for supporting small projects in the renewable energy sector, especially in the agricultural sector, where conventional funding is limited.

Digital financial solutions, such as blockchain technologies and smart contracts, can play a significant role in financing renewable energy sources, which ensure transparency of transactions, automate financial obligations, and reduce the risk of fraud. This opens up new opportunities for investors and project developers to interact without intermediaries, such as banks, which significantly reduces project implementation costs. P. Vionis & T. Kotsilieris (2024) explored the role of digital financial technologies, such as blockchain and smart contracts, in financing renewable energy projects, noting that these technologies can significantly reduce costs and increase the transparency of financial transactions, while reducing the risk of fraud. P. Zhao *et al.* (2022), in turn, noted that digital tools open up new opportunities for farms that do not have access to conventional financing, providing them with transparent and accessible mechanisms for attracting investment.

In agriculture, renewable energy can be a powerful driver for reducing energy costs and increasing energy independence (Havrysh *et al.*, 2022). This is especially important for farmers who have limited access to funding for the introduction of solar panels or biogas plants. Government support in the form of subsidies and soft loans, and international funding from institutions such as the EBRD and the World Bank, can play an important role in this. A.T. Hoang *et al.* (2021) emphasised that such funding is important for reducing the initial cost of renewable energy plants, which is especially important for small farms. These findings coincide with the conclusions of the current study, and the importance of state support for stimulating the transition to renewable energy sources was also emphasised. However, more attention has been paid to innovative financial mechanisms such as green bonds, rather than just conventional subsidies.

However, as the experience of Ukraine shows, the introduction of financial mechanisms to support renewable energy faces certain difficulties. High initial costs for renewable energy plants, an unstable legal framework and a lack of long-term funding are the main obstacles to the development of this area (Andreitsev *et al.*, 2024). In addition, it is necessary to solve the issues of bureaucratic procedures and create more attractive conditions for investors. T.S. Kabel & M. Bassim (2020) investigated barriers to the development of renewable energy, in particular, the economic and legal factors that slow down this process. High initial costs for renewable energy plants, an unstable legal framework, and difficulties in obtaining long-term funding are the main obstacles that need to be overcome to achieve sustainable development in this industry. The present article identifies these obstacles, indicating that legal and economic instability are the primary reasons constraining the advancement of renewable energy. Consequently, the present results align with the researcher's conclusions, but the current study emphasised financial methods that may assist in surmounting these obstacles.

▸ Conclusions

The results showed that progress in the use of renewable energy sources in EU countries, in particular, in Germany, Poland, Spain, the Netherlands, and France, is significant. In particular, in the EU, electricity production from renewable sources increased from 750.9 thousand GWh in 2014 to 1,130.2 thousand GWh in 2023, which indicates the sustainable development of this sector. However, Ukraine is experiencing slow growth, where electricity production from renewable sources remained in the range of 10.1-16.8 thousand GWh from 2014 to 2020. Such a difference in the pace of development between Ukraine and the EU may be conditioned not only by technical and economic barriers, but also by insufficient state support and limited access to funding. An important segment is the financing of renewable energy in agriculture. Given the seasonality of agricultural production and the specific needs for autonomous energy solutions, agriculture faces difficulties in financing renewable energy projects due to high start-up costs. Government subsidies and concessional lending are important support mechanisms. However, for small and medium-sized farms, these mechanisms are not available due to limited funding and bureaucratic obstacles.

Total consumption of renewable energy by agriculture in the EU increased from 27.5 thousand GWh in 2014 to a peak of 38.8 thousand GWh in 2021, after which it decreased to 36.1 thousand GWh in 2023. In Ukraine, from 2014 to 2020, a gradual increase in the use of renewable electricity in the agricultural sector was also recorded – from 173.1 GWh in 2014 to 321.7 GWh in 2020. The mechanisms of financing renewable energy in the agricultural sector of EU countries, in particular Germany, France, Poland, and the Netherlands, were analysed. The experience of these countries demonstrates that an effective combination of financial incentives, such as subsidies, tax breaks, and auction mechanisms, contributes to the development of sustainable energy in agriculture, reducing greenhouse gas emissions and increasing the energy independence of farms. The research demonstrated that the implementation of renewable energy in the agricultural sector, exemplified by RWE in Germany and Astarta-Kyiv in Ukraine, serves as an effective mechanism for enhancing energy efficiency, diminishing reliance on conventional energy sources, and lowering greenhouse gas emissions. Further research may include expanding the analysis to other regions and evaluating the effectiveness of various financial mechanisms at the national level.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Інноваційні фінансові інструменти для стимулювання розвитку відновлювальної енергетики

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▸ **Анотація.** У цьому дослідженні були розглянуті сучасні фінансові механізми та інструменти, які сприяють інвестиціям у сектори відновлюваної енергетики. Методологія дослідження включала статистичний аналіз даних про виробництво та споживання електроенергії з відновлюваних джерел у Європейському Союзі та Україні. Результати дослідження продемонстрували, що в Європейському Союзі спостерігається значне зростання виробництва електроенергії з відновлюваних джерел, в першу чергу завдяки ефективним стратегіям залучення інвестицій. На противагу цьому, Україна демонструє непослідовні моделі розвитку сектору відновлюваної енергетики. Аналіз підкреслив взаємозв'язок між надійною фінансовою базою та успішним впровадженням відновлюваної енергетики. У той час як Європейський Союз впровадив узгоджені механізми, що дають очевидні результати, ландшафт відновлюваної енергетики в Україні відображає наслідки менш стабільної фінансової інфраструктури. Загальна генерація в Європейському Союзі зросла з 750,9 тис. ГВт-год у 2014 році до 1130,2 тис. ГВт-год у 2023 році, що свідчить про стабільне розширення сектору. Найбільш перспективними фінансовими інструментами стали зелені облігації, які дозволяють залучати значні капітальні інвестиції в екологічні проекти, та енергетичні кооперативи, що сприяють децентралізації енергетики та розвитку місцевих громад. Проаналізовано механізми фінансування відновлюваної енергетики в аграрному секторі країн Європейського Союзу, зокрема Німеччини, Франції, Польщі та Нідерландів. Досліджено впровадження відновлюваної енергетики в аграрному секторі на прикладі компаній RWE (Німеччина) та «Астарта-Київ» (Україна). Показано, що державні субсидії, пільгове кредитування, міжнародні інвестиції та механізми корпоративного фінансування відіграли важливу роль у подоланні бар'єрів. Забезпечення сталого фінансування відновлюваної енергетики в Україні потребує комплексного підходу, включаючи активне залучення державних, приватних та міжнародних інвестицій

▸ **Ключові слова:** альтернативні джерела; екологічна стійкість; інвестиційні механізми; державне регулювання; кліматична політика

Received: 28.10.2024. Revised: 29.01.2025. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.100

Ekonomika APK, 32(2), 100-112

UDC 657.47:631.16

Cost accounting and costing of crop production in agribusinesses of various forms of ownership

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► **Abstract.** The purpose of this study was to analyse the effectiveness of cost accounting methods and costing of production in crop enterprises of varying scales and forms of ownership. To achieve this aim, 5 agricultural enterprises in Ukraine engaged in crop production were examined: a small farm Zeleny Lan, a medium-sized farm Sonyachnyi Sad, a large agricultural holding AgroProstir, a cooperative enterprise Zernovy Kray, and a private enterprise Zolotyi Kolos. The research methods included an analysis of the financial statements of these enterprises for the period 2021-2023, the use of spreadsheets to structure data, and statistical analysis to assess cost variability. Particular attention was given to the comparison of costing methods, such as direct costing, the equivalent unit method, and automated accounting systems Debet+ and Enterprise Resource Planning (ERP). The impact of automation on the accuracy of calculations, transparency of financial transactions, and opportunities for cost optimisation was assessed. The challenges associated with manual accounting in small farms, the lack of integration of overhead costs in private enterprises, and the need for cooperation to reduce costs in medium-sized and cooperative enterprises were analysed. The paper proposes ways to improve accounting practices, including the implementation of

► **Suggested Citation**: Demchuk, O., Moshkovska, O., Ihnatenko, T., Romashko, O., & Kuzub, M. (2025). Cost accounting and costing of crop production in agribusinesses of various forms of ownership. *Ekonomika APK*, 32(2), 100-112. doi: 10.32317/ekon.apk/2.2025.100.

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automated cost accounting systems, standardisation of cost calculation, expansion of cooperative opportunities, and the development of innovative approaches to cost management using geoinformation technologies, the Internet of Things, and artificial intelligence. It is concluded that enhancing accounting methods is key to increasing the efficiency of agricultural enterprises and their adaptation to modern market conditions

▸ **Keywords:** agriculture; enterprise economics; resource management; cooperatives; seasonal costs; information systems

▸ Introduction

Cost accounting in crop production is a crucial aspect of effective agribusiness management, influencing the profitability of enterprises regardless of their size or form of ownership. The contemporary conditions of agricultural management – characterised by the introduction of new technologies and ongoing legislative changes – necessitate the continuous improvement of cost accounting methods. The core problem addressed in this study is the identification of optimal cost accounting approaches that can ensure accuracy, efficiency, and effectiveness in cost management across various types of agricultural enterprises.

V. Zhuk *et al.* (2023) analysed the consequences of Russia's military aggression against Ukrainian agribusiness, particularly focusing on the disruption of logistics and the destruction of industrial facilities. The authors proposed a simplified methodology based on five accounting tools – inventory, documentation, valuation, accounts and balance sheet, and reporting – to enable the rapid determination of direct losses. Experimental calculations demonstrated that the object-based methodology yields significantly higher and more reliable loss estimates (e.g., USD 63.88 billion for real estate) compared to the rapid global assessments conducted by organisations such as the World Bank. The study underscores the advantages of comprehensive expert evaluations over generalised assessments, advocating for their application in compensation and recovery processes.

N. Bondarenko & N. Rizchenko (2019) examined methods of accounting for costs and output in crop production, highlighting the necessity of implementing modern information systems to enhance accounting accuracy. The authors emphasised the importance of precise accounting of production costs and crop output to improve the efficiency of accounting practices in agricultural organisations. The competitive environment necessitates a detailed examination of sector-specific characteristics, including the utilisation of specialised labour resources, the influence of environmental factors, the length of production cycles, and the availability of standardised documentation and reporting (Musayeva *et al.*, 2024). A thorough understanding of these factors contributes to the timely provision of accurate and comprehensive data on the volume of produce, its pricing, and associated production costs, thereby supporting effective current, operational, and strategic management of agricultural enterprises.

O. Demchuk (2023) substantiates the necessity of assessing accounting costs from both financial and managerial perspectives, as well as recognising the influence of technological and agrobiological characteristics on the organisation of accounting. The study stresses the inclusion, within the unit cost of finished crop production calculated through the management accounting system, of not only actual resource expenditures but also estimated costs and lost profits. The study by I. Sukhonosenko & V. Gryn (2021) identifies the primary functions of accounting for agricultural production costs, with a particular focus on cost management and the monitoring of production activities. The authors underline the significance of treating costs as objects of both financial and managerial accounting, addressing contemporary challenges such as enhancing production efficiency and improving product quality. Additionally, the study considers the impact of external factors, particularly market volatility and insufficient material incentives. The authors emphasise the role of accounting as the principal means of obtaining reliable information essential for economic decision-making and risk forecasting in agricultural operations.

The study by H. Alkarawy & N. Al-Ssadi (2023) explores the assessment and structuring of production cost accounting and the regulation of biological costs in agriculture, alongside the verification of the accuracy of production cost calculations for the objective determination of cost indicators and management of production processes. Within an agricultural firm, biological costs were evaluated based on both the actual and fair value of products, enabling the identification of artificially reduced or inflated profits during the sale of produce. Additionally, production and sales costs were categorised by cost items, which enhanced the informational and administrative aspects of accounting and increased the overall efficiency of agricultural production.

Despite the substantial body of existing research, several gaps remain in the scientific literature that warrant further investigation. One such gap concerns the adaptation of cost accounting methods to the specific characteristics of different types of agricultural enterprises, including small farms and large agricultural holdings. Moreover, the impact of accounting process automation on the effectiveness of cost management remains insufficiently studied. The implementation of new technologies – particularly information systems for cost accounting – has the potential to significantly transform cost management practices (Hnatyshyn *et al.*, 2025), yet this area has not received adequate attention in academic discourse.

The literature analysis also highlights the need for the development of new accounting methods that reflect contemporary technological and economic changes. The integration of information systems into accounting processes can considerably enhance the accuracy and speed of data processing, which is vital for effective cost management (Marmul *et al.*, 2023). In light of these considerations, this study aims to analyse and improve existing cost accounting methods in crop production, as well as

to develop new approaches aligned with the current demands of agribusiness.

The objective of this research was to examine the features of cost accounting, its organisation, and the methods of calculating the cost of crop production in agricultural enterprises of various sizes and forms of ownership. To achieve this objective, the following tasks were undertaken: analysing existing approaches to cost accounting in crop enterprises; assessing the influence of enterprise size and ownership form on the organisation of cost accounting; developing recommendations for optimising product cost calculation.

▸ Materials and methods

In the conducted study, 5 agricultural enterprises in Ukraine engaged in crop production were selected. The research was conducted throughout 2023 and comprised several stages: data collection, data processing, and analysis of the results. The sample included agricultural enterprises of varying sizes and forms of ownership: a small farm Zelenyi Lan with a cultivated land area of up to 50 hectares (Clarity Project, 2022); a medium-sized farm Soniachnyi Sad with an area of 100-200 hectares (Clarity Project, 2023a); and a large agricultural holding AgroProstir with more than 1,000 hectares of cultivated land (Clarity Project, 2023b). In addition, a cooperative agricultural enterprise Zernovyi Krai (Clarity Project, 2023c) and a private agricultural enterprise Zolotyi Kolos, with an area of up to 500 hectares (Clarity Project, 2023d), were included in the analysis.

The inclusion criteria for the sample were: active involvement in crop production, availability of financial statements for the period 2021-2023, and willingness to cooperate and participate in the study. For the enterprise Zelenyi Lan, the analysis was conducted for the years 2021-2022, in contrast to the other enterprises, for which reporting data covered the period 2022-2023. This deviation was due to data availability limitations for Zelenyi Lan, which prevented full comparability across a uniform time frame. The study accounted for this limitation in the interpretation of results, and conclusions were adjusted accordingly to consider potential effects of economic changes between the different periods.

Data collection was conducted through the analysis of the official financial statements of the selected enterprises. These statements provided information on the structure of costs, methods of cost accounting, the utilisation of information systems, and the degree of automation in accounting processes. To supplement this information and gain a deeper understanding of internal operations, direct observation of accounting practices at the enterprises was undertaken. This facilitated a more detailed understanding of resource utilisation and cost management practices. A key focus of the analysis was the examination of cost accounting methods and the application of financial reporting standards. In small farms, national accounting systems with minimal automation were predominant, whereas large agricultural holdings employed international standards, enabling more detailed cost control and compliance with investor requirements.

Computers equipped with cost accounting software, such as Debet+ and SAP Enterprise Resource Planning (ERP), were used for both data collection and processing. Data were input into spreadsheets created using Microsoft Excel for subsequent analysis. The use of Microsoft Excel enabled convenient structuring and systematisation of the information, facilitating further statistical analysis. The analysis of the collected data employed various statistical techniques; in particular, correlation analysis was used to determine the relationship between the level of automation in accounting processes and the efficiency of cost management. The application of diverse methods of data collection and analysis provided a comprehensive overview of the state of cost accounting in crop production across agricultural enterprises in Ukraine. The study enabled the identification of key factors influencing the efficiency of cost accounting and helped to determine possible avenues for its optimisation.

▸ Results

Financial analysis of agricultural enterprises of different forms of ownership. The financial analysis of each enterprise commenced with an assessment of the structure of assets and liabilities. It was found that the micro-enterprise Zelenyi Lan has a significantly simpler asset structure compared to the other enterprises under study (Clarity Project, 2022). At both the beginning and end of the reporting period (2021-2022), the enterprise's assets consisted primarily of current assets, including inventories valued at UAH 5 thousand at the beginning of the year and UAH 8 thousand at the end. The absence of non-current assets indicates a limited level of investment activity within the enterprise. The liabilities of Zelenyi Lan also remained stable during the analysed period, with a modest increase in retained earnings from UAH 4 thousand to UAH 7 thousand. This reflects a positive financial outcome but suggests constrained potential for further expansion or development (Table 1).

Table 1. Structure of assets and liabilities of enterprises (thousands UAH)

Indicator	Zelenyi Lan (2021-2022)	Soniachnyi Sad (2022-2023)	AgroProstir (2022-2023)	Zernovyi Krai (2022-2023)	Zolotyi Kolos (2022-2023)
Fixed assets, thousand UAH	0	30.80	14,537	14,819	0
Current assets, thousand UAH	8	473.10	77	6,520	9
Equity, thousand UAH	7	-78.40	14,514	29,057	-538
Short-term liabilities, thousand UAH	0	582.30	100	15,135	666
Net profit (loss), thousand UAH	2	156.80	-32	-586	-17

Source: created by the authors

The small enterprise Soniachnyi Sad exhibited notable changes in its asset structure over the reporting period. At the beginning of the year, the enterprise did not possess fixed assets; however, by the end of the period, it had made substantial investments in the modernisation of production and expansion of its production capacity. This reflects the enterprise's commitment to development and improving operational efficiency. Simultaneously, a decrease in current assets may suggest a reduction in inventories or receivables, which is common when resources are actively allocated towards modernisation efforts. Despite these shifts, the enterprise successfully reduced its losses, indicating effective financial management and a gradual improvement in its financial standing. This case exemplifies how appropriate investment decisions can drive sustainable development, even under resource constraints (Clarity Project, 2023a).

AgroProstir, in contrast, maintained a substantial volume of non-current assets, indicative of prior large-scale investments in long-term assets such as equipment and infrastructure. However, no new investments were recorded during the reporting period, which may suggest either a temporary pause in investment activity or the absence of immediate capital needs. The decline in current assets may be attributed to reduced working capital or a fall in accounts receivable. The company's reported losses imply that it was unable to effectively leverage its resources to generate profit. Nevertheless, the considerable asset base suggests a potential to restore financial stability in the future, provided that management practices are improved (Clarity Project, 2023b).

Zernovyi Krai reported a significant increase in current assets, likely linked to an expanded customer base or increased sales on deferred payment terms. These developments may reflect the success of the enterprise's commercial strategies. However, the simultaneous rise in short-term liabilities indicates potential challenges in managing current assets and accounts payable. To ensure long-term sustainability, the enterprise must enhance its cash flow management to mitigate liquidity risks (Clarity Project, 2023c).

Zelenyi Lan, while demonstrating stable performance, continues to face constraints in development due to the absence of investment in long-term assets (Clarity Project, 2022). In contrast, Zolotyi Kolos requires urgent intervention to improve financial sustainability and restore profitability (Clarity Project, 2023d). The broader macroeconomic context remains a critical factor influencing the overall production costs faced by enterprises. For agricultural producers, the prices of fuel, lubricants, and energy are especially significant, as they constitute a major portion of expenditure. A 12% increase in energy prices over the reporting year had a marked impact on production costs across all surveyed enterprises. This effect was particularly pronounced for Soniachnyi Sad and Zernovyi Krai, both of which exhibit a high degree of mechanisation and operate with a large volume of equipment.

Features of cost accounting in crop production. Financial analysis of agricultural enterprises provides insights not only into their asset and liability structures but also into the effectiveness of cost management throughout the production cycle. The enterprises examined in this study demonstrate varying volumes and compositions of costs, which can be attributed to differences in their size, form of ownership, and the specific nature of their operations. Among the key cost-related aspects are seasonality, the use of fertilisers and fuel, and equipment depreciation, all of which significantly influence production costs.

The seasonality of costs in crop production has a pronounced impact on the structure and volume of financial investment in agricultural enterprises, particularly during the sowing, crop maintenance, and harvesting phases (Makhazhanova *et al.*, 2024). The sowing campaign is a period of heightened expenditure for all enterprises, marked by concentrated costs for seeds, fertilisers, and fuel. Zelenyi Lan, operating with limited resources, allocates a substantial portion of its budget – approximately 50-60% – to basic inputs such as seeds and fertilisers. The enterprise primarily relies on internal reserves or short-term loans to finance these expenses (Clarity Project, 2022). Soniachnyi Sad channels investment into the modernisation of machinery and the application of plant protection products, with approximately 55-60% of its annual expenditure directed toward increasing production efficiency and reducing costs in later stages (Clarity Project, 2023a). AgroProstir, the largest enterprise in the sample, invests heavily in hybrid seeds and operates a large fleet of machinery. The sowing campaign accounts for around 55% of its annual expenses (Clarity Project, 2023b). The cooperative Zernovyi Krai benefits from joint procurement arrangements, securing discounts on fertilisers and fuel, thereby reducing its overall expenses. Its sowing campaign constitutes approximately 50% of the annual budget (Clarity Project, 2023c). Zolotyi Kolos, facing financial difficulties and a high credit burden, spends about 60% of its annual expenditure on sowing. This significantly constrains its liquidity and hinders its ability to maintain stable operations throughout the year (Clarity Project, 2023d).

The next stage of the production cycle is crop care, which includes the costs associated with fertiliser application, plant protection, and inter-row tillage. In the micro-enterprise Zelenyi Lan, these costs remain moderate due to the use of simplified technologies, comprising approximately 15% of the annual budget (Clarity Project, 2022). Soniachnyi Sad invests in advanced agricultural technologies aimed at reducing expenditure on fertilisers and plant protection products, with these costs amounting to 18% of the annual budget (Clarity Project, 2023a). AgroProstir allocates significant resources to agricultural automation, which has enabled the optimisation of crop care expenses, maintaining them at around 15% of annual costs (Clarity Project, 2023b). Zernovyi Krai, benefiting from the cooperative model of investment distribution, achieves a similar level of efficiency, with crop care expenses representing 18% of the annual budget (Clarity Project, 2023c). Zolotyi Kolos, constrained by limited resources, utilises the most affordable plant protection products available, with crop care accounting for 20% of its annual expenditures (Clarity Project, 2023d).

At the harvesting stage, agricultural enterprises face high costs related to the use of machinery, fuel, and labour. In the case of Zelenyi Lan, harvesting expenses are

relatively low due to the limited production volume, with 15-20% of the annual budget allocated to the hiring of machinery. Soniachnyi Sad incurs fuel and labour costs amounting to 20-25% of its annual expenditure, reflecting its reliance on seasonal labour during the harvest period. AgroProstir allocates approximately 20% of its budget to harvesting, which includes significant outlays for fuel and machinery – some of which is rented due to the scale of operations (Clarity Project, 2023b). Through the cooperative use of machinery, Zernovyi Krai manages to reduce harvesting costs to 17% of its annual budget (Clarity Project, 2023c). Zolotyi Kolos, lacking its own equipment, is entirely dependent on machinery rentals, which increases its harvesting expenses to 25% of the annual budget (Clarity Project, 2023d).

The uneven distribution of costs throughout the year imposes a significant burden on financial turnover, often compelling enterprises to resort to loans or utilise internal reserves. This issue is particularly relevant for enterprises such as Soniachnyi Sad and Zolotyi Kolos, where seasonal financing needs lead to an increased credit burden. In contrast, AgroProstir, through the adoption of automation and innovative technologies, has succeeded in reducing operational costs, thereby contributing to the stabilisation of its financial position.

An examination of cost accounting practices reveals that Zelenyi Lan, a small farm cultivating up to 50 hectares, employs simplified accounting methods based primarily on Microsoft Excel. The enterprise focuses mainly on the calculation of direct costs – namely seeds, fertilisers, and fuel – which comprise over 50-60% of its annual budget. However, this approach has several limitations, including the absence of automation, the complexity of manual processes, and the inability to perform in-depth cost analysis. These shortcomings complicate financial management, particularly in the face of rising prices for fertilisers and energy. The implementation of even basic-level information systems could significantly enhance cost efficiency, enabling Zelenyi Lan to generate more accurate data for financial planning and control (Clarity Project, 2022).

The medium-sized farm Soniachnyi Sad (100-200 hectares) has achieved notable success through the implementation of the Debet+ system. This system enabled the automation of cost accounting at key production stages: sowing, crop care, and harvesting. The application of precision farming technologies facilitated optimal use of fertilisers and plant protection products, thereby reducing resource losses. Fertilisers and fuel represent approximately 40% of the enterprise's annual expenses. Debet+ contributes to the accuracy of financial data, minimises the risk of human error, and enhances decision-making in resource planning (Clarity Project, 2023a).

AgroProstir, a large agricultural holding managing over 1,000 hectares, utilises the SAP ERP system. This system integrates data across income, expenses, inventories, and production operations. A key advantage of ERP implementation is the ability to analyse costs in real time and automatically plan expenditure in accordance with seasonal fluctuations. In 2023, equipment and fertiliser costs constituted between 40-50% of the annual budget. Additional SAP modules support the consolidation of large-scale datasets and assist in identifying opportunities for cost reduction. Despite the high implementation and maintenance costs, investments in accounting automation enhance the competitiveness of the holding (Clarity Project, 2023b).

The cooperative enterprise Zernovyi Krai is in the process of modernising its information systems, transitioning from 1C to Debet+. Automation enables transparent accounting of cooperative expenditures and ensures an equitable distribution of costs among members. The principal expense category is fuel and technical support, which accounts for up to 17% of the annual budget. The adoption of precision farming technologies has led to a 15% reduction in fertiliser costs through optimised application. The cooperative model provides access to discounts and advanced technologies, thereby enhancing overall profitability (Clarity Project, 2023c).

The private agricultural enterprise Zolotyi Kolos (up to 500 hectares) operates with limited financial resources, which has resulted in manual accounting practices using Excel. A substantial share of its expenditure is allocated to fertilisers (60% of the budget) and equipment rental (up to 25%). The lack of automation increases the risk of ineffective planning and complicates cost control. Even the basic implementation of information systems could significantly improve accounting efficiency, reduce overall expenses, and enhance the enterprise 's liquidity (Table 2).

Table 2. Comparison of costs, automation and accounting features in agricultural enterprises

Enterprise	Accounting programme	Seeding campaign (% of budget)	Crop care (% of budget)	Harvest (% of budget)	Automation
Zelenyi Lan	Excel	50-60	15	15-20	None
Soniachnyi Sad	Debet+	55-60	18	20-25	Partial
AgroProstir	SAP ERP	55	15	20	Full
Zernovyi Krai	Debet+	50	18	17	Partial
Zolotyi Kolos	Excel	60	20	25	None

Source: created by the authors

Macroeconomic factors such as inflation, rising energy prices, and currency fluctuations have a significant impact on the cost structures and overall financial performance of agricultural enterprises in Ukraine. The analysis below illustrates how these factors have affected specific enterprises, based on relevant financial data. For the micro-enterprise Zelenyi Lan, inflation – which reached 8% – resulted in increased costs for essential inputs such as fertilisers and plant protection products (Clarity Project, 2022). This had a notable impact on the

enterprise's operating costs. Due to the absence of long-term contracts and limited capacity for bulk purchasing, Zelenyi Lan is unable to benefit from significant supplier discounts. Furthermore, a 5% increase in the exchange rate raised the cost of imported plant protection products, placing additional pressure on the enterprise's budget.

In the case of the medium-sized enterprise Soniachnyi Sad, the effects of inflation and a 12% increase in energy prices were more pronounced, owing to the enterprise's greater reliance on machinery and corresponding expenditure on fuel (Clarity Project, 2023a). Additionally, exchange rate volatility contributed to higher costs for imported fertilisers, which represent a substantial portion of the enterprise's expenses. To mitigate these challenges, Soniachnyi Sad has actively invested in precision agriculture technologies, aiming to reduce dependency on input volumes and optimise resource use. Nevertheless, intense competition in the domestic market has constrained the enterprise's ability to increase product prices, thereby reducing overall profitability.

As a large agricultural holding with access to export markets, AgroProstir has partially benefited from the devaluation of the national currency, which has increased its revenue in hryvnia terms. However, inflation at 8% and a 12% rise in energy prices have led to higher costs for fertilisers and plant protection products (Clarity Project, 2023b). The enterprise's substantial equipment inventory also results in significant energy expenditure. Consequently, management is actively considering the implementation of new technologies to optimise energy use and enhance the efficiency of cost management in order to mitigate the adverse impact of macroeconomic factors on overall financial performance.

The cooperative enterprise Zernovyi Krai has likewise benefited from the devaluation of the hryvnia, due to its export-oriented operations. Nevertheless, high energy prices and inflationary pressure have increased the cost of its resource base, creating a financial burden, particularly during the sowing campaign. Zernovyi Krai actively employs cooperative mechanisms to reduce the cost of fertiliser and fuel procurement, which partially offsets the impact of external economic pressures (Clarity Project, 2023c). In light of these challenges, the enterprise is also planning to invest in energy-efficient technologies that could contribute to long-term cost reduction.

In contrast, the private enterprise Zolotyi Kolos, which operates solely within the domestic market, does not benefit from currency fluctuations (Clarity Project, 2023d). Rising energy prices and inflation have driven up the costs of fertilisers and fuel, negatively affecting profitability. The enterprise is compelled to take out loans to finance its operating expenses, thereby increasing its reliance on credit and limiting opportunities for future development. Due to the absence of export activity, Zolotyi Kolos remains especially vulnerable to macroeconomic shocks and rising input costs, which it cannot consistently offset through price adjustments.

In summary, macroeconomic factors such as inflation, exchange rate volatility, and increasing energy costs affect agribusinesses differently depending on their size and market orientation. Export-oriented enterprises such as AgroProstir and Zernovyi Krai enjoy certain advantages from foreign exchange earnings, whereas domestically focused enterprises like Zolotyi Kolos are more heavily impacted by rising costs, which undermines their competitiveness and financial resilience.

Approaches to calculating the cost of production in agricultural enterprises of different sizes using information systems. Direct costs – such as seeds, fertilisers, and fuel – constitute the core of production expenditures in agricultural enterprises. However, the approach to cost accounting varies considerably depending on the size of the enterprise and the degree of digitalisation in use. At Zelenyi Lan, direct costs are calculated manually, with limited granularity. For instance, seeds are purchased without consideration of zonal requirements, and fertilisers are applied without reference to soil characteristics. All expenses are recorded as aggregate figures, which restricts opportunities for planning and cost optimisation. Furthermore, overhead costs – such as labour and equipment maintenance – are largely excluded from the accounting process. This omission compromises the accuracy and completeness of full production cost calculations, resulting in a less realistic financial picture.

In contrast, the medium-sized farm Soniachnyi Sad benefits from the implementation of the Debet+ accounting system, which enables more detailed and accurate cost tracking. Seed usage is accounted for by zone, reflecting the needs of specific field plots. Fertiliser requirements are calculated automatically based on agrochemical analyses, and the system presents cost data dynamically over time. In relation to fuel, Debet+ ensures transparent recording of transport and refuelling costs, which is particularly critical during the sowing campaign. Overhead costs, including logistics and maintenance, are allocated through automated modules, thereby enhancing the accuracy, transparency, and comprehensiveness of the enterprise's cost data.

In AgroProstir, both direct and overhead costs are integrated within a unified SAP ERP system, offering the highest level of detail and analytical capacity. For instance, the cost of hybrid seeds is calculated with consideration of transportation expenses and yield forecasts. Fertiliser requirements are determined through integration with a geographic information system (GIS), enabling tailored application based on the agrochemical characteristics of soils in each region. Overhead costs are automatically allocated via ERP modules according to crop area or production volume, encompassing logistics, equipment depreciation, and administrative expenses. This high level of automation enables real-time cost optimisation and supports strategic decision-making (Kuzub *et al.*, 2023).

The cooperative enterprise Zernovyi Krai employs the Debet+ system to facilitate joint procurement of seeds and fertilisers. Costs are allocated among cooperative members in proportion to the area of land cultivated. Fertilisers are used efficiently due to the centralised approach, allowing for considerable cost savings. Overhead expenses, such as machinery maintenance and logistics, are included and automatically distributed among members, promoting transparency and improving cost-efficiency across the cooperative.

By contrast, at Zolotyi Kolos, cost accounting remains highly simplified due to the absence of automated systems. Seeds and fertilisers are procured in minimal quantities,

and key overhead costs – including equipment depreciation and personnel expenditure – are largely overlooked. This results in reduced accuracy of cost calculations and hampers effective financial management. Elevated costs for fuel and machinery rental further intensify financial strain, increasing the enterprise's vulnerability and jeopardising its operational stability. Costing methods play a critical role in determining the accuracy of cost estimation and, ultimately, the financial efficiency of an enterprise. Depending on the scale of operations, the availability of automated systems, and the selected cost accounting strategy, agricultural enterprises adopt various approaches to determine production costs.

Zelenyi Lan employs a direct costing method. This is the most basic approach, allowing the enterprise to account only for primary cost items such as seeds, fertilisers, and fuel. Cost accounting is conducted without the allocation of overheads, significantly reducing the accuracy of total cost estimation. The absence of automation further limits the enterprise's ability to disaggregate costs by crop type or cultivated area. Although this method is suitable for small farms due to its minimal financial and technical requirements, it restricts strategic planning and hinders informed decision-making.

Zolotyi Kolos similarly relies on direct costing. Owing to financial constraints, the enterprise lacks access to automated systems and, therefore, performs all cost calculations manually. As a consequence, overhead costs – particularly those associated with equipment depreciation and maintenance – are either insufficiently considered or entirely excluded. This undermines the assessment of actual profitability and constrains the enterprise's capacity to accurately forecast and manage future expenses.

In contrast, Soniachnyi Sad complements direct costing with the functionalities of the Debet+ system. This system partially automates the costing process, accounting for seasonal cost fluctuations, field-specific conditions, and logistical expenses. As a result, the enterprise is able to include not only seeds and fertilisers but also pesticides, fuel, and administrative overheads in its cost analysis. This more comprehensive approach enables the farm to assess the profitability of individual crops more effectively and to reduce losses through the optimisation of field operations.

Large enterprises such as AgroProstir utilise the equivalent unit method, which provides a high degree of accuracy in cost calculations by incorporating both direct and overhead costs. The SAP ERP system automatically allocates these costs across different crops or plots by analysing yield, soil quality, and resource usage. This method enables the enterprise to assess the cost and profitability of individual crops, thereby informing strategic decisions. However, the implementation and maintenance of an ERP system entail substantial financial investment, rendering this approach largely inaccessible to smaller farms.

In Zernovyi Krai, cost calculation is performed through the automated Debet+ system, which facilitates the distribution of shared cooperative costs among participants. Centralised procurement of seeds, fertilisers, and fuel contributes to cost optimisation, while the system ensures transparent allocation. The cost calculation method is based on a proportional approach, wherein each member' costs are determined according to their respective land area. This supports the minimisation of losses and promotes the rational use of shared resources.

Automated systems such as Debet+ and ERP offer enhanced transparency and accuracy, significantly reducing the influence of human error (Table 3). For instance, Debet+ at Soniachnyi Sad enables the seasonal and zonal tracking of expenses – capabilities that are not available to enterprises relying on manual accounting. In large companies such as AgroProstir, ERP enhances the efficiency of cost calculations and facilitates the modelling of future expenditures. Conversely, enterprises without automation, such as Zolotyi Kolos, face considerable challenges in cost accounting, along with a heightened risk of errors. These limitations undermine financial planning and reduce overall operational efficiency.

Table 3. Comparison of cost calculation methods in enterprises of different scales and forms of ownership

Enterprise	Calculation method	Cost elements taken into account	Advantages/Disadvantages
Zelenyi Lan	Direct counting	Seeds, fertilisers, fuel	Easy to implement; no overhead costs
Soniachnyi Sad	Direct calculation + Debit+	Seeds, fertilisers, pesticides, fuel	Partial automation; takes seasonality into account
AgroProstir	Equivalent units method	All direct and overhead costs	High accuracy, high implementation cost
Zernovyi Krai	Debit+, basic distribution	Shared resources: machinery, fertilisers	Transparent distribution of costs between participants
Zolotyi Kolos	Direct counting	Fertilisers, fuel	Labour intensive, low accuracy

Source: created by the authors

The automation of costing is essential for the effective management of agricultural enterprises. Those utilising advanced methods – such as the equivalent unit method employed by AgroProstir – demonstrate greater accuracy in cost calculation and an enhanced capacity to analyse the profitability of individual products. For smaller enterprises, it is advisable to begin with the implementation of basic information systems. Even at a foundational level, such systems can significantly improve cost control and contribute to greater financial stability.

Ways to improve cost accounting and costing of crop production. Enterprises of all sizes should consider the phased introduction of automated accounting systems, tailored to their financial capacities. Small farms, such as Zelenyi Lan, are encouraged to adopt affordable software solutions – particularly basic versions of Debet+ – to

automate the recording of direct costs (seeds, fuel, fertilisers) and enhance the accuracy of cost calculations. For medium and large enterprises, such as Soniachnyi Sad and AgroProstir, it is advisable to implement specialised cost accounting modules within ERP systems. These should ideally be integrated with geographic information system (GIS) technologies to facilitate detailed zonal analysis and more precise cost allocation.

1. Standardisation of costing methods. There is a need to develop uniform methodological guidelines for cost calculation that are appropriate for enterprises of varying sizes. For small farms, a focus on direct cost accounting will ensure basic financial transparency and simplicity. Medium-sized enterprises should apply cost distribution methods by crop, incorporating considerations of seasonality and resource usage. For large agricultural holdings, the equivalent unit method – with an emphasis on real-time analytics and forecasting – is most suitable, supporting strategic planning and profitability analysis.

2. Optimisation of accounting processes through cooperation. Small enterprises are advised to form accounting cooperatives that offer shared access to automated systems and professional financial analysis. For instance, the creation of cooperatives comprising multiple farmers using a unified accounting platform such as Debet+ can significantly reduce the cost of software and data processing. This cooperative model enhances cost-efficiency, enables access to expert support, and promotes the adoption of modern accounting practices among smaller producers.

3. Integration of innovative technologies. Large agricultural holdings and medium-sized farms are well-positioned to adopt innovative accounting solutions, including artificial intelligence (AI)-based modules capable of forecasting costs and optimising resource consumption. The integration of Internet of Things (IoT) sensors in agricultural fields facilitates the automated collection of data on the agrochemical composition of soil, thereby enabling more accurate calculation of fertiliser requirements and improving overall cost efficiency.

4. Financial support for accounting automation. There is a clear need for the development of government support programmes to encourage the automation of accounting processes. Initiatives similar to the "Affordable Loans 5-7-9%" programme could be extended to include grants or low-interest loans for small and medium-sized agricultural enterprises. Such financial instruments would help alleviate the burden of initial investment in modern accounting systems and encourage broader adoption of digital technologies.

5. Development of training programmes for personnel. Staff training should be prioritised to ensure effective use of automated systems and modern accounting techniques. Specialised courses and training programmes for employees of agricultural enterprises – particularly accountants and agronomists – can significantly enhance awareness and understanding of advanced accounting tools, automated solutions, and data analytics in cost management. A skilled workforce is essential for maximising the benefits of technological integration.

6. Monitoring and regular review of accounting policies. Agricultural enterprises should conduct regular internal audits of their accounting policies and cost calculation methodologies. This ensures alignment with evolving market conditions, technological advancements, and legislative requirements. Continuous review promotes the relevance and reliability of financial data, supporting effective management and strategic planning.

The implementation of these measures will enhance the accuracy of accounting, the transparency of cost calculations, and the financial stability of agricultural enterprises, ultimately strengthening their competitiveness in the face of modern challenges.

International experience in optimising costs in agriculture through modern technologies. In European Union countries such as Germany and France, cost accounting methodologies in agriculture are undergoing significant modernisation, driven by the adoption of advanced information technologies (Gocht *et al.*, 2016). In Germany, the implementation of cost management software enables agricultural enterprises to automate accounting processes at every stage of the production cycle – from the procurement of raw materials to harvesting. This ensures both accuracy and transparency in determining production costs and supports more effective resource management (Hentschl *et al.*, 2023). French agricultural enterprises actively utilise ERP systems to integrate all aspects of their operations, thereby streamlining financial transactions and minimising operational costs. For example, the company Vignerons de la Méditerranée has implemented the SAP Business One ERP system to optimise business processes and reduce overall costs (Boussemart & Parvulescu, 2021). Such systems enable agricultural companies to reduce administrative expenses while enhancing production efficiency.

Modern information systems in the EU offers several key advantages. Firstly, they automate cost accounting procedures, significantly reducing the time required for data processing and the preparation of financial reports. This is particularly beneficial for large agricultural enterprises that handle substantial volumes of data. Secondly, these systems provide real-time access to financial and operational data, enabling managers to make timely and well-informed decisions regarding cost management and investment planning. The present study highlights that the automation of accounting operations enhances the accuracy of cost accounting and supports compliance with international standards. When agricultural enterprises implement modern technologies, they are better positioned to minimise operational costs and improve their overall competitiveness in a global market (Pushak *et al.*, 2021).

Strategic cost management in agribusiness in the United States and Canada is underpinned by the implementation of energy-efficient technologies and integrated resource management systems, which optimise energy and resource usage to enhance profitability. Numerous agricultural enterprises in the United States are investing in solar panels, geothermal heating and cooling systems, and energy recovery technologies (Clark, 2020). These innovations contribute significantly to the reduction of energy costs, which typically represent a major component of operating expenses in the agricultural sector. In parallel, farmers are adopting technologies to improve irrigation efficiency, thereby optimising water usage and minimising related costs. These strategies have

demonstrated substantial economic benefits. Despite increasing energy and resource prices, farmers are able to increase gross income by three to four times, raise profit margins by up to 2.5 times, and significantly reduce transportation and storage expenses. Investments in such technologies generally pay off within two to three years, while stable demand for agricultural products reduces financial risks and strengthens overall business profitability.

Canada is also progressively adopting strategies to reduce energy-related costs in agriculture (Jamil *et al.*, 2023). Agricultural enterprises are deploying advanced production management systems that automate energy storage and distribution operations. In addition, the adoption of smart farming technologies has enabled full automation and integration of agricultural activities – from soil data collection to energy consumption monitoring – within a unified management framework. This approach not only lowers operational costs but also improves production efficiency by enabling accurate forecasting and resource optimisation.

The current study underlines the value of investing in modernisation as a means of reducing production costs, as exemplified by Soniachnyi Sad. Similar to practices observed in the United States and Canada, the enterprise focuses on the adoption of modern technologies to reduce operational expenses. This demonstrates that, even under financial constraints, well-considered investments in energy efficiency can support sustainable development and enhance profitability. The broader implementation of such technologies in agriculture can increase competitiveness and ensure long-term financial resilience.

State support plays a vital role in the development of small and medium-sized agricultural enterprises in countries such as Spain and the Netherlands. Spain operates a comprehensive subsidy system aimed at supporting farmers engaged in organic agriculture, the use of renewable energy, and the implementation of environmentally friendly practices (Marini *et al.*, 2023). Subsidies are allocated for the modernisation of equipment, the adoption of new technologies, and the integration of precision farming systems. In addition, preferential credit schemes targeted at young farmers facilitate the creation of new agricultural enterprises and improve access to finance. Notably, the Programa de Desarrollo Rural (Rural Development Programme) in Spain provides funding for farmers who practise organic and environmentally sustainable agriculture. Similarly, the Green Climate Agreement in the Netherlands offers subsidies to support the transition to renewable energy and the reduction of CO_2 emissions in agriculture. These forms of government support enhance the competitiveness of farmers in domestic markets and aid their integration into international markets.

The Netherlands places particular emphasis on state initiatives that encourage innovation and environmental sustainability within the agricultural sector. Small farms receive financial assistance to implement advanced technologies, such as energy-efficient greenhouses, automated irrigation systems, and the use of biodegradable materials in agricultural production (Brazhnyk *et al.*, 2022). Across the European Union – particularly in countries such as Italy, Austria, Germany, France, Sweden, and Poland – specialised support programmes are available for farmers operating in regions with challenging climatic conditions. These include subsidies for mountainous areas, incentives for the adoption of renewable energy, agricultural insurance schemes, and funding for the development of sustainable farming technologies. Such initiatives contribute to the sustainability of agricultural production by helping farmers reduce operational costs, mitigate environmental and economic risks, and adapt to extreme weather conditions. An essential component of these support strategies is the provision of advisory services and training programmes delivered through state institutions. These initiatives equip farmers with the knowledge and skills necessary to adopt modern technologies and best practices in cost management, production efficiency, and sustainability.

This experience mirrors Ukrainian agribusiness support initiatives, which likewise provide subsidies and soft loans to small and medium-sized agricultural enterprises. Soniachnyi Sad, for instance, has utilised soft loans to expand its production capacity. During the reporting period, the enterprise secured financing through preferential loans, enabling investment in fixed assets – specifically, the acquisition of new equipment aimed at improving the efficiency of production processes. Owing to the favourable terms of this financing, including low interest rates, the company was able to enhance its production capabilities, which in turn led to increased productivity and reduced production costs. Such forms of state support enable farmers to access financing that might otherwise be unavailable due to limited financial resources. This strategy not only strengthens the position of small and medium-sized enterprises within the agricultural sector but also contributes to their long-term sustainability. It plays a crucial role in ensuring national food security and improving access to export markets.

▸ Discussion

The results of this study underscore the importance of adapting cost accounting methods to the specific characteristics of different types of agricultural enterprises. Using the example of small farms such as Zelenyi Lan, the research demonstrates that simplified accounting methods can be effective in ensuring operational stability. Conversely, large agricultural holdings require detailed and comprehensive cost accounting at each stage of the production process. This highlights the need for a differentiated approach to cost management, tailored to the scale and complexity of the enterprise.

N. Bondarenko & N. Rizchenko (2019) emphasised the significance of effective cost management and investment in fixed assets as a means of securing the financial stability of agricultural enterprises. The findings of the present study confirm this assertion through the example of Soniachnyi Sad, which achieved positive financial outcomes by investing in the modernisation and optimisation of its production processes. This case illustrates that, even in conditions of limited financial resources, stability and development can be attained through well-informed investment decisions. Similarly, O. Demchuk (2023) highlighted the importance of sound financial resource management in ensuring enterprise stability. The current study corroborates this view, particularly in the case of

AgroProstir, where inadequate management of current assets contributed to reduced liquidity and financial losses. This reinforces the necessity of strategic planning and the optimisation of financial resources to maintain the stability of large agricultural enterprises.

Moreover, the findings align with the conclusions of J. Tingey-Holyoak *et al.* (2023), whose research on decision-making processes in viticulture in Australia's Riverland region also identified the importance of modern technologies and automation in accounting practices for improving cost management efficiency. Both studies emphasise the role of access to timely and accurate accounting information, and the integration of data-driven technologies, in supporting strategic decision-making during periods of economic uncertainty. In particular, the example of Soniachnyi Sad demonstrates that investment in financial management automation can reduce costs and increase profitability, consistent with findings on the importance of accounting data in enhancing the sustainability of viticultural enterprises in the Riverland.

The study by L. Bassotto *et al.* (2022), which applies the theory of the firm to enhance cost management within the agricultural sector, reveals notable parallels with the findings presented in this article. Both studies highlight cost accounting as a fundamental tool for improving the economic efficiency of agricultural enterprises. In each case, the adopted methodologies distinguish between different types of costs – particularly cash and general costs – thereby enabling a more accurate analysis of the financial condition of enterprises (Boiko *et al.*, 2024). The findings of the present study reinforce the relevance of cost differentiation for improved resource management and the optimisation of financial indicators. This aligns with the Custeio Agro approach, which advocates for precise cost assessment in agriculture to support efficient management decisions.

The study by H.-Y. Lee *et al.* (2020), which explores the integration of green accounting through the lens of intellectual capital in agribusiness, reveals significant parallels with the findings presented in this article concerning the implementation of modern cost accounting methods. Both studies underscore the critical role of accounting systems in enhancing the efficiency of cost management and improving the financial performance of agricultural enterprises. The present article highlights that automation of accounting processes and the adoption of modern information systems contribute to cost reduction and increased competitiveness (Shevchuk & Radelytskyy, 2024). This aligns with the concept of green accounting, which integrates environmental costs and intellectual resources – such as innovation and organisational change – as essential components of sustainable agribusiness development. Both perspectives support the need for an interdisciplinary approach to simultaneously advance financial and environmental performance.

The study by A. Jayaraman *et al.* (2023), which analyses the role of social capital in farm production companies in India, also shares commonalities with the findings of this article on cost management in agricultural enterprises. Both studies stress the importance of interpersonal relationships, leadership, and organisational structure as critical factors for business success. In the Indian context, social capital – encompassing social networks and effective leadership – has been shown to enhance coordination and marketing capabilities. Similarly, this article emphasises that optimising accounting processes and automating cost management significantly contribute to improving the financial outcomes of agricultural enterprises. Together, these approaches demonstrate that effective enterprise management – whether driven by social capital or technological innovation – is fundamental to enhancing performance in the agricultural sector.

Thus, the research confirms that the implementation of modern information systems and the optimisation of cost accounting methods are key factors in enhancing the efficiency of agricultural enterprises, irrespective of their scale. This is particularly evident in large agricultural holdings, where the automation of accounting processes contributes to improved resource management and the minimisation of financial losses. At the same time, for small farms such as Zelenyi Lan, the adaptation of simplified accounting methods supports the maintenance of financial stability under resource-constrained conditions. Future research should focus on analysing the influence of external economic factors – such as inflation and exchange rate fluctuations – on the effectiveness of cost management. It is also advisable to develop practical recommendations for the adoption of innovative technologies in cost accounting, with a view to further strengthening the sustainability and competitiveness of agribusiness.

▸ Conclusions

The analysis of cost structures in Ukrainian crop enterprises reveals that cost accounting and costing practices vary significantly depending on the size of the enterprise, the degree of automation, and market orientation. Small farms are typically characterised by reliance on manual accounting and direct cost calculation methods, which reduce the precision of cost estimates and limit managerial capacity. Medium-sized enterprises benefit from the implementation of systems such as Debet+, which facilitate the structured allocation of both direct and overhead costs. Large enterprises, employing ERP systems, are able to conduct high-precision accounting and integrate cost data within a unified analytical framework for resource optimisation. The cooperative model used by Zernovyi Krai demonstrates the advantages of centralised cost management and equitable resource allocation among members, thereby enhancing both transparency and profitability.

The automation of accounting processes and the selection of appropriate costing methodologies are critical for effective management of crop enterprises across different scales. While small farms – such as Zelenyi Lan and Zolotyi Kolos – primarily rely on direct counting, which limits their accounting accuracy and decision-making capabilities, medium and large enterprises – such as Soniachnyi Sad and AgroProstir – employ automated Debet+ and ERP systems. These tools enable detailed, real-time cost tracking, transparent cost allocation, and rational management of overheads. The cooperative model of Zernovyi Krai further illustrates the financial and operational benefits of shared resource management. The results confirm that even basic automation

can serve as a crucial first step toward enhancing the competitiveness of small enterprises.

The adoption of improved cost accounting and costing methods is a vital mechanism for increasing the efficiency of agricultural enterprise management. The development of unified standards, expansion of automation, promotion of cooperative models, and integration of innovative technologies will collectively improve the accuracy of accounting and cost transparency. These measures will not only enhance enterprise profitability but also contribute to the broader development of the agricultural sector in the face of evolving market and macroeconomic challenges. Future research should explore models for adaptation to macroeconomic fluctuations, evaluate the effectiveness of state support measures, and examine the impact of emerging technologies on production costs.

Acknowledgements
None.

Funding
None.

Conflict of interest
None.

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Облік витрат і калькулювання собівартості продукції рослинництва в агробізнесі різних форм власності

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► **Анотація.** Метою даного дослідження було проаналізувати ефективність методів обліку витрат і калькулювання собівартості продукції у підприємствах рослинництва різного масштабу та форми власності. Для досягнення мети було досліджено 5 аграрних підприємств в Україні, що займаються рослинництвом: мале фермерське господарство «Зелений Лан», середнє фермерське господарство «Сонячний Сад», великий агрохолдинг «АгроПростір», кооперативне підприємство «Зерновий Край» та приватне підприємство «Золотий Колос». Методи дослідження включали аналіз фінансової звітності цих підприємств за 2021-2023 роки, використання електронних таблиць для структурування даних та статистичний аналіз для оцінки варіабельності витрат. Особливу увагу приділено порівнянню методів калькулювання витрат, таких як прямий підрахунок, метод еквівалентних одиниць, автоматизовані облікові системи Дебет+ і Enterprise Resource Planning (ERP). Оцінено вплив автоматизації на точність розрахунків, прозорість фінансових операцій та можливості оптимізації витрат. Проаналізовано виклики, пов'язані із ручним обліком у малих господарствах, відсутністю інтеграції накладних витрат у приватних підприємствах та необхідністю кооперації для зниження собівартості в середніх і кооперативних підприємствах. У роботі запропоновано шляхи вдосконалення обліку, включаючи впровадження автоматизованих систем обліку витрат, стандартизацію калькуляції собівартості, розширення можливостей для кооперації та розвиток інноваційних підходів до управління витратами за допомогою геоінформаційних технологій, Інтернету речей і штучного інтелекту. Зроблено висновок про те, що удосконалення методів обліку є запорукою підвищення ефективності агропідприємств та їхньої адаптації до сучасних ринкових умов

► **Ключові слова:** сільське господарство; економіка підприємства; управління ресурсами; кооперативи; сезонні витрати; інформаційні системи

Received: 29.06.2024. Revised: 30.11.2024. Accepted: 13.03.2025.

EKONOMIKA APK

https://doi.org/10.32317/ekon.apk/2.2025.113

Ekonomika APK, 32(2), 113-126

UDC 338.27:332.1

Forecasting regional development of the agricultural sector in the context of economic instability

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▸ **Abstract.** The purpose of the study was to assess the impact of economic factors on the agricultural sector of the Dnipropetrovsk Oblast for the period 2021-2024, identify key trends and develop approaches to improving the economic stability of the region. Within the framework of the study, methods of regression analysis, econometric modelling, and scenario approach were applied to assess the dynamics of yield, the structure of acreage, investment activity, and the share of the agricultural sector in the gross regional product. The results of the study showed that the share of the agricultural sector in the gross regional product ranged from 7.5-8.76% during the analysed period. The highest rate of 8.76% was recorded in 2022 due to a 46% reduction in the total gross regional product compared to 2021. The volume of agricultural production decreased by 33.9% in 2022, but partially recovered in 2023, reaching UAH 32.5 billion. The regression analysis showed that an increase in the fuel price by 1 UAH/l reduces the wheat yield by 0.2 cwt/ha, and an increase in the inflation rate by 1% leads to a decrease in the yield by 0.3 cwt/ha. Scenario analysis showed possible consequences of changes in economic conditions: in a pessimistic scenario, wheat yields may fall to 36.08 cwt/ha by 2028. The significance of the results obtained lies in the possibility of using them to form strategies for the recovery

▸ **Suggested Citation**: Khrystenko, O., Oliinyk, T., Tabatskova, G., Potochylova, I., & Rybachuk, V. (2025). Forecasting regional development of the agricultural sector in the context of economic instability. *Ekonomika APK*, 32(2), 113-126. doi: 10.32317/ekon.apk/2.2025.113.

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and development of the agricultural sector in conditions of economic instability. It was proposed to focus on attracting foreign investment, diversifying crops and introducing energy-efficient technologies to increase the sustainability of the region. The results of the study also highlighted the importance of government support, which accounted for 25% of total investment in 2023, which contributed to a partial recovery in economic activity in the agricultural sector

▸ **Keywords:** gross output; investment activity; crop diversification; crop insurance; crop structure

▸ Introduction

The relevance of this study is conditioned by the need to ensure the stable development of the agricultural sector of Ukraine in the context of economic instability, which is caused by the impact of global and internal crisis phenomena, such as war, inflation, rising resource prices, and changes in international trade relations. The agricultural sector is a strategically important sector that ensures food security, creates a significant share of gross domestic product, and acts as a key source of income for a significant number of the population.

However, the instability of the economic environment affects the efficiency of agricultural enterprises, reduces their competitiveness, and creates risks for investment activities (Berxolli *et al.*, 2023). Under these conditions, there is a need to develop scientifically based approaches to forecasting the development of the agricultural sector, which would consider the specifics of regional features and the influence of macroeconomic factors.

The problems of optimising the structure of assets and capital of Ukrainian agricultural enterprises caused by macroeconomic instability, low investment attractiveness and lack of transparent market rules after the cancellation of the moratorium on land sales were discussed in the study by N. Barabash & T. Pashkuda (2021). The researchers, using models of correlation of financial indicators, found that the agricultural sector provides 15-20% of the gross domestic product of Ukraine annually, but its development was limited by financial risks and lack of innovative management mechanisms. Risk management methods, the introduction of modern financial instruments, and the impact of technology investment on industry stabilisation remain insufficiently studied.

Ukraine's integration into the European market and the challenges of war significantly complicate ensuring the competitiveness of the agricultural sector (Shebanin *et al.*, 2024). S. Kozlovskyi *et al.* (2023) investigated these aspects by developing an economic and mathematical model based on fuzzy set theory, which allowed assessing competitiveness considering quantitative and qualitative factors. The results of their study included a forecast of competitiveness until 2026, which showed an increase in efficiency in the context of European integration. Gaps that require additional research include improvements in the methodology for assessing military factors such as logistics, energy, and fertiliser delivery.

The impact of wartime and instability on the agricultural sector significantly complicates its development. S. Moshenskyi *et al.* (2024) focused on the stagnation of livestock production and the decline in crop growth rates caused by political and economic instability, in particular, the events of 2014 and 2022. The researchers developed recommendations for minimising the negative impact of corruption, developing innovation, and attracting investment to support the agricultural sector. Gaps that require further study include improved wartime support policies and effective resource management to address the effects of economic instability.

Martial law and economic instability significantly affect the financial support of the agricultural sector, which creates numerous challenges for its functioning and development (Pylypenko *et al.*, 2025). D. Titov & V. Oleksienko (2024) focused on changing conventional financing mechanisms, in particular lending, due to high risks and uncertainty. The researchers highlighted the importance of new financial instruments, such as international aid, grants, risk insurance, and crowdfunding, which could contribute to the stability of the agricultural sector. However, gaps that required additional research included adapting these tools to the specific conditions of Ukraine and implementing insurance mechanisms, considering the risks of military operations.

The unstable state of agricultural entrepreneurship in Ukraine, in particular during martial law, significantly complicated the strategic development of this industry. O. Kovbasa (2024) studied the components of the strategic development of agricultural entrepreneurship, paying attention to the disparities in the structure of production, technological support, regional differences, and the problems of adaptation of enterprises to modern challenges. The researcher emphasised the need to improve the risk management system through the introduction of digital technologies, diversification of risk management tools, and strengthening cooperation with stakeholders. The gaps that required further research included the impact of digitalisation on the effectiveness of strategic management and the integration of environmental aspects into the development of agricultural entrepreneurship.

Current economic trends, in particular, globalisation, climate change, and market instability, have significantly complicated the management of the development of the agricultural sector (Wang *et al.*, 2024). N. Petrukha & V. Karashko (2024) focused on the need to introduce innovative technologies that would help to improve the efficiency and sustainability of production. The researchers developed an algorithm for implementing innovative technologies and a model for adopting technologies in conditions of uncertainty. The importance of ensuring adequate funding and support from the state and international organisations was also emphasised. Further research requires adapting technologies to the specific conditions of different regions, and integrating innovations into a single production process.

Regional differentiation and economic instability created significant challenges for the agricultural sector (Boiko *et al.*, 2024). H. Syrotiuk (2022) investigated the features of the development of the agricultural sector of the

Lviv Oblast, drawing attention to the imbalance between crop production and animal husbandry, which negatively affects food security and employment of the population. The researcher proposed approaches to improving state support, in particular, through compensation for the costs of machinery, seeds, and livestock maintenance. Further analysis requires the integration of innovative technologies into production processes and increasing the effectiveness of agricultural policy at the regional level.

The purpose of the study was to develop econometric models for predicting the development of the agricultural sector of Ukraine in conditions of economic instability, considering the influence of macroeconomic and regional factors. To achieve this goal, the following tasks were defined: to analyse the dynamics of the main indicators of the agricultural sector, such as yield, production structure and investment activity; to assess the impact of economic instability on the sustainability and efficiency of agricultural enterprises.

▸ Materials and methods

This study represented an applied, analytical research aimed at assessing the impact of economic factors on the agricultural sector of the Dnipropetrovsk Oblast. The time frame covered the period from 2021 to 2024, as 2021 was the base period for analysis, reflecting stable economic conditions before the start of significant challenges related to military operations and economic instability. This allowed comparing indicators before and during the crisis conditions, identifying key trends and the impact of external factors on the agricultural sector. Dnipropetrovsk Oblast was selected for the study because of its strategic role in Ukraine's agricultural sector, its significant contribution to the country's gross agricultural output, and the high level of impact of economic and social challenges on regional development. This helped to investigate the adaptive capabilities of the region in the context of macroeconomic changes.

The main sources of information were official statistics (Dnipro Agro Group, n.d.; Bayer, 2021; Latifundist, 2023; Main Department of Statistics in the Dnipropetrovsk Oblast, 2023), economic forecasts (State Statistics Service of Ukraine, 2022; 2023), data from the National Bank of Ukraine (2022; 2023; 2024), and information obtained in the process of econometric modelling (Fuel prices: how..., 2022; Kudynenko, 2022; How the average..., 2023). The study focused on key indicators such as agricultural output, gross regional product, investment activity, crop yields, and structural changes in acreage (Ministry of Economy of Ukraine, 2020; National Institute for Strategic Studies, 2024). The analysis included an assessment of economic and social changes affecting the agricultural sector. As part of the study, the share of the agricultural sector in the gross regional product of the Dnipropetrovsk Oblast for 2021-2023 was analysed (1):

$$S = \frac{agricultural\ products}{gross\ regional\ product} \cdot 100\%, \quad (1)$$

where S – share of the agricultural sector in the gross regional product, expressed as a percentage; *agricultural products* – total volume of products produced in the agricultural sector (in monetary terms); *gross regional product* – total volume of products and services produced in the region (in monetary terms).

This analysis allowed assessing the dynamics of the contribution of the agricultural sector to the economic stability of the region and its adaptive capabilities in conditions of economic instability. The results of the analysis of the share of the agricultural sector in the gross regional product determined its role in ensuring the economic stability of the region and the impact of key economic factors on the development of agriculture. This contributes to the achievement of the research goal, as it provides sound data for developing effective strategies for the recovery and development of the agricultural sector in conditions of economic instability. To analyse the influence of individual factors on wheat yield, a regression model was used, which considered changes in yield depending on variables such as fuel price and inflation rate (2):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon, \quad (2)$$

where Y – projected wheat yield (cwt/ha); X_1 – fuel price (UAH/l); X_2 – inflation rate (%); β_0, β_1, β_2 – regression coefficients that determine the effect of independent variables on the dependent one; ε – random error.

The model calculated how changes in each of these indicators affect yield, helping to predict the dynamics of the indicator depending on economic conditions. This provided a more accurate forecast based on changes in key macroeconomic indicators. To analyse the dynamics of wheat yield in the Dnipropetrovsk Oblast, the average value formula was used, which allowed calculating the average yield value for the projected period (3):

$$Average = \frac{\sum Yi}{n}. \quad (3)$$

The study also used scenario analysis to assess the possible impact of economic factors on agricultural production. Three scenarios were identified: optimistic, baseline, and pessimistic, which considered various possible changes in fuel costs, inflation rates, and overall economic conditions (4):

$$D_{wholesale} = yields \cdot area \cdot price. \quad (4)$$

The scenario approach allowed assessing the prospects for the development of the agricultural sector depending on the future dynamics of macroeconomic conditions. In addition, a comparative analysis of the investment structure was carried out, which helped to assess the impact of various types of investment – public, private, and foreign – on the development of the agricultural sector. This analysis identified key factors for the stability of the agricultural sector in the context of economic instability. For data processing and construction of econometric models, modern software tools were used, in particular Excel and SPSS, which provided the possibility of qualitative data analysis, building models and forecasts. The tools helped to accurately assess the impact of factors on economic indicators and identify opportunities for adapting the agricultural sector to modern challenges.

▸ Results

Dnipropetrovsk Oblast is one of the leading regions of Ukraine in terms of agricultural production. Agricultural

land of the region covers an area of about 2.54 million hectares, which is a significant part of its territory. According to this indicator, the Dnipropetrovsk Oblast is among the top 5 regions of Ukraine. The main areas of agricultural production in the region are the cultivation of cereals (wheat, barley, corn) and oilseeds (sunflower, rapeseed), which form the basis of the agricultural sector. The cultivation of grain and oilseeds in the Dnipropetrovsk Oblast covers significant areas of agricultural land, which makes this region one of the key producers in Ukraine. The main crops are wheat, barley, sunflower, and rapeseed, which provide a high level of production for both domestic consumption and export (Penkova & Kharenko, 2023).

In 2021, the yield of the main crops was also high. Winter wheat provided 49.4 cwt/ha, sunflower and winter rapeseed – 28.6 cwt/ha each, and winter barley – 37.8 cwt/ha. The total area of agricultural land in the region occupied for these crops allows maintaining the stability of the agricultural sector even in difficult conditions (Bayer, 2021). In 2022, despite economic difficulties, about 99 thous. t of grain and oilseeds were harvested. The yield of winter wheat was 48.6 cwt/ha, rapeseed – 39.3 cwt/ha, and barley – about 31.5 cwt/ha. These results indicate a stable level of production, even in difficult conditions. In 2023, the region showed high yield indicators. Sunflower had a yield of up to 26.3 cwt/ha in some plots, and the area of its sowing amounted to more than 12 thous. ha. Winter wheat provided a yield of 52.4 cwt/ha, harvested from more than 12 thous. ha. Rapeseed showed an average yield of 35.7 cwt/ha on an area of about 578 ha (Dnipro Agro Group, n.d.).

In 2024, farmers of the Dnipropetrovsk Oblast achieved significant success in harvesting. More than 60 thous. t of winter barley was harvested from 21 thous. ha, with an average yield of 29 cwt/ha. Winter wheat provided even higher indicators: more than 109 thous. t from 35 thous. ha, with an average yield of 32.3 cwt/ha. In addition, more than 21 thous. t of winter rapeseed was harvested from more than 14 thous. ha, while the yield was 16 cwt/ha. Sunflower also showed a significant improvement: about 1.1 mln. t was harvested from the area with an average yield of 21 cwt/ha, which exceeds the previous year's figure of 16 cwt/ha. In total, 1,808.6 thous. t of winter and spring wheat were harvested in 2024, with an average yield of 3.3 t/ha. These achievements demonstrate the stability and development of the region's agricultural sector (Poltorak *et al.*, 2023: Shostak, 2024).

During 2021-2023, the volume of agricultural production in the Dnipropetrovsk Oblast showed significant fluctuations, reflecting the impact of both positive and negative factors on the agricultural sector. In 2021, the volume of production amounted to UAH 41.6 billion, which indicates stability in the region's agriculture. This indicator highlights the important role of the agricultural sector as one of the key sources of economic growth in the region. In 2022, there was a significant reduction in production volumes, which decreased to UAH 27.5 billion. The decrease of 33.9% compared to the previous year was caused by a number of negative factors, in particular, military operations, economic instability, and disruption of logistics chains. These circumstances significantly affected the productivity of the agricultural sector, reducing its efficiency. In 2023, according to expectations, the volume of agricultural production increased to UAH 32.5 billion, which reflects a partial recovery of the sector after previous losses. Despite this, the indicators remained below the level of 2021, which indicates the need for further stabilisation and adaptation of the agricultural sector to new conditions. Recovery was made possible by improved production conditions, well-coordinated work of enterprises, and a gradual return on investment in the industry (Main Department of Statistics in the Dnipropetrovsk Oblast, 2023).

During 2021-2024, the Dnipropetrovsk Oblast experienced significant changes in the structure of yields of the main agricultural crops, which were conditioned by economic challenges and the impact of military operations. In 2021, winter wheat occupied 497 thous. ha, sunflower – 601.3 thous. ha, winter rapeseed – 86.8 thous. ha, corn – 303 thous. ha, and winter barley – 90 thous. ha. In 2022, the area under winter wheat decreased to 457.2 thous. ha, sunflower – to 541.5 thous. ha, corn – to 275.5 thous. ha, and under winter barley – to 75 thous. ha, while winter rapeseed increased to 104 thous. ha, which emphasises its growing attractiveness. In 2023, the area under winter wheat decreased even more, to 406.4 thous. ha, sunflower grew to 621.69 thous. ha, winter rapeseed also showed positive dynamics, reaching 125.2 thous. ha, and the area under corn and winter barley decreased to 218.06 thous. ha and 65 thous. ha, respectively. In 2024, the area under winter wheat increased to 455.2 thous. ha, which is 108.1% compared to 2023. Sunflower showed stable growth, reaching 702.7 thous. ha (113% by 2023), while the area under winter rapeseed increased to 248.69 thous. ha, which is 356.8% compared to the previous year. The area under corn also increased to 293.13 thous. ha, which is 108.3% compared to 2023. Such changes indicate the adaptation of the agricultural sector to new conditions and an emphasis on the most promising crops, such as sunflower and rapeseed (Main Department of Statistics in the Dnipropetrovsk Oblast, 2024). In general, these changes in the structure of crops indicate the need to adapt the agricultural sector to new realities, in particular, through crop diversification and optimisation of production processes. Sunflower and rapeseed proved to be the most promising crops that provide stable demand and profitability, while the area under wheat and corn was reduced due to economic and climate challenges (Latifundist, 2023).

The gross regional product of the Dnipropetrovsk Oblast showed significant fluctuations during 2021-2023. This was due to stable events in peacetime and problems caused by war and economic instability. As evidenced by the stable economic development of the region and its significant contribution to the gross regional product of Ukraine in 2021, the gross regional product of the region amounted to UAH 582.363 million. This indicator highlights the importance of the region as one of the most important economic centres of the country. However, in 2022, amid military operations and significant economic shocks, the gross regional product fell to UAH 313.83 million. This decline, which was about 46% compared to 2021, reflected the serious challenges facing the region's economy. The negative effects of the war affected all industries, including industry, agriculture, transport, and infrastructure (State Statistics Service of Ukraine, 2022). In 2023, there was a partial recovery of gross regional

product to the level of UAH 398.732 million (State Statistics Service of Ukraine, 2023). Despite this growth, the figures are still below the level of 2021. Figure 1 shows graphically how the gross regional product in the region changed during this period.

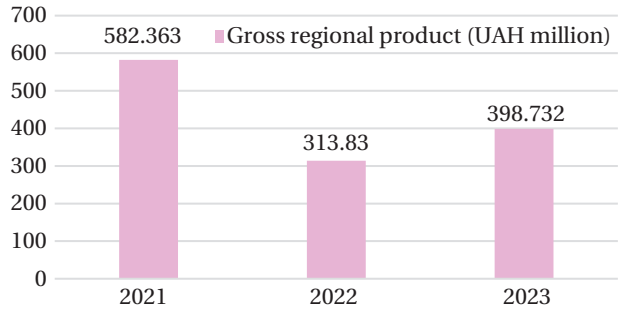

Figure 1. Indicators of gross regional product for the period 2021-2023
Source: compiled by the authors

This indicates a gradual improvement in the economic situation, which, however, requires additional efforts to stabilise and develop the regional economy. Dnipropetrovsk Oblast continued to play an important role in Ukraine's economy, demonstrating resilience and recovery potential. To assess the contribution of the agricultural sector to the gross regional product of the Dnipropetrovsk Oblast for the period 2021-2023, the method of calculating the share of agricultural products in the gross regional product based on equation (1) was used. This approach allows analysing the current dynamics and dependence of the development of the agricultural sector on the economic conditions of the region:

$$S2021 = \frac{41.6}{582.363} \cdot 100\% = 7.5\%. \quad (5)$$

In 2021, the share of the agricultural sector in the gross regional product was 7.5%, which reflects the stable development of agriculture against the background of overall economic growth in the region:

$$S2022 = \frac{27.5}{313.830} \cdot 100\% = 8.76\%. \quad (6)$$

In 2022, the share of the agricultural sector increased to 8.76% due to a reduction in the total gross regional product due to military operations and the economic crisis. This highlights the sustainability of the agricultural sector as a key element of the regional economy in times of crisis:

$$S2023 = \frac{32.5}{398.732} \cdot 100\% = 8.15\%. \quad (7)$$

In 2023, the share of the agricultural sector was 8.15%. Despite the partial economic recovery, the indicator remained below the level of 2021, which indicates the need for additional investment, state support, and innovative solutions for the sustainable development of the industry. According to the results of the analysis, the share of the agricultural sector in the gross regional product of the Dnipropetrovsk Oblast during 2021-2023 underwent significant changes, reflecting the impact of economic and social factors on the development of the region. In 2021, the share of the agricultural sector was about 7.5%, which indicates the stable development of agriculture against the background of the overall economic growth of the region. In 2022, as a result of military operations and the economic crisis, gross regional product declined significantly, but the agricultural sector showed relative resilience, increasing its share to 8.76%. This underlines the importance of the agricultural sector as one of the key elements of the regional economy in times of crisis. In 2023, against the background of a partial recovery in gross regional product, the share of the agricultural sector was 8.15%. Despite some improvement in indicators, the level remained lower than in pre-war 2021. This shows that the agricultural sector continues to adapt to new conditions, but its stable development requires additional investment, state support and innovative solutions. Thus, the agricultural sector remained an important stabilising factor in the economy of the Dnipropetrovsk Oblast, providing a significant contribution to the gross regional product even in difficult conditions.

In the period 2021-2023, there was a gradual decrease in the number of people employed in agriculture in the Dnipropetrovsk Oblast, which indicates the impact of economic challenges and changes in working conditions in the region. In 2021, the agricultural sector employed about 87.6 thous. people, which accounted for approximately 9.5% of total employment, emphasising the importance of agriculture as an important source of jobs. In 2022, the number of employees decreased to 81 thous. people (8.9% of total employment) due to the negative consequences of the war, which significantly affected all aspects of agricultural activities, including labour resources. In 2023, this decline continued, and the number of employed people decreased to 75 thous. (8.5% of total employment), which indicates prolonged economic instability and the need to adapt to new realities. Figure 2 graphically shows the dynamics of the number of people employed in agriculture in the Dnipropetrovsk Oblast.

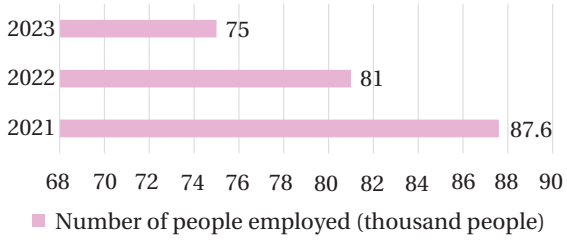

Figure 2. Number of people employed in agriculture in Dnipropetrovsk Oblast 2021-2023
Source: compiled by the authors

Investment activity also changed during this period. In 2021, the total volume of investment in the agricultural sector amounted to about UAH 8.5 billion, of which 20% was accounted for by public investment, 15% – by foreign investment, and 65% – by private investment, which indicated a significant role of the private sector. In 2022, investment decreased to UAH 5.2 billion, while the share of public investment increased to 25%, and foreign investment decreased to 10% due to instability. The private sector continued to provide 65% of funding, while maintaining its leading role. In 2023, the total volume of

investments reached UAH 6 billion, reflecting a partial recovery of the industry. Public investment remained at 25%, foreign investment rose to 15%, and private investment accounted for 60%, demonstrating the sector's adaptation to new conditions. Thus, despite the challenges, agriculture in the Dnipropetrovsk Oblast continued to play an important role in the region's economy, but further development requires additional measures to support and stimulate investment (State Statistics Service of Ukraine, 2023).

In the period 2021-2023, the inflation rate in Ukraine experienced significant fluctuations, reflecting the influence of both internal and external factors. In 2021, inflation was 10% year-on-year, exceeding the target range defined by the National Bank of Ukraine (2022). The price increase was driven by global factors such as supply chain disruption due to the COVID-19 pandemic, rising energy and raw material prices, and domestic factors including rising consumer demand and rising production costs. Record harvests, the strengthening of the hryvnia, and the NBU's monetary policy, which raised its key policy rate from 6% to 9% to contain price pressures, had a positive impact on containing inflation.

In 2022, inflation rose sharply to 26.6% in annual terms, which was the result of a full-scale war. Infrastructure destruction, supply chain disruption, rising production costs, and exchange rate fluctuations have put significant pressure on prices. Despite the difficult conditions, the measures of the National Bank of Ukraine (2023), including fixing the hryvnia exchange rate and raising the discount rate to 25%, helped to contain inflationary processes. In addition, the government imposed a moratorium on raising tariffs for housing and communal services, which also helped to reduce price pressure. At the end of the year, the price growth rate stabilised due to the establishment of logistics and the expansion of food supply.

In 2023, inflation slowed significantly to 5.1% in annual terms, which was the result of comprehensive measures taken by the National Bank of Ukraine (2024), good harvests, and a stable situation in the foreign exchange market. The decline in price growth is explained by improved exchange rate expectations, curbing administrative prices, and reducing business costs. Core inflation fell to 4.9%, while non-food prices even fell by 0.1%. The slowdown in the growth of the cost of services and durable goods further contributed to the stabilisation of the price situation. Thus, in 2023, inflation in Ukraine returned to controlled levels due to the effective actions of the National Bank and the government, despite the difficult conditions of previous years.

The dynamics of the cost of wheat cultivation in the Dnipropetrovsk Oblast depended on macroeconomic factors, such as inflation, an increase in the cost of fuel and agricultural resources. In 2021, the average cost of one tonne of wheat was UAH 1,825. This level of spending remained stable due to moderate inflation (10%) and relatively low fuel prices. For example, the average price of diesel fuel was 21.18-22.6 UAH/l, which allowed farmers to maintain the profitability of production through effective cost management. In 2022, inflation reached 26.6%, and diesel fuel prices rose to a record 56.36 UAH/l in May, which led to an increase in the cost of wheat to 2,278.5 UAH/t, or 24.9% more than in the previous year (Fuel prices: How…, 2022; Kudynenko, 2022). The rise in the price of fuel used for the operation of agricultural machinery and transportation of products has become one of the key factors for rising costs. For example, a 150% increase in the cost of diesel fuel significantly increased the cost of field work. In addition, fertiliser prices increased by 40%, which increased the cost of growing crops by 18%. Military action and logistics disruptions have also contributed to additional pressure on manufacturers. In 2023, inflation slowed to 5.1%, while fuel prices stabilised at 43.4 UAH/l in June (Fig. 3). However, the cost of wheat remained high – 2,268.2 UAH/t (How the average…, 2023; National Institute for Strategic Studies, 2024).

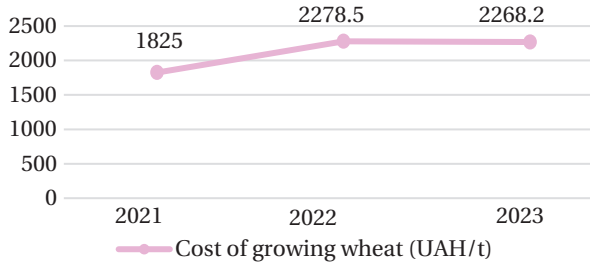

Figure 3. Cost of wheat cultivation in Dnipropetrovsk Oblast in 2021-2023
Source: compiled by the authors

This suggests that previous economic shocks still affected farmers' spending. Low purchase prices for cereals forced producers to change the structure of crops in favour of more cost-effective crops, such as sunflower and rapeseed, but this also required additional investment and limited opportunities for reducing production costs. Rising fuel and fertiliser prices combined with high inflation in 2022 were a crucial factor in raising the cost of wheat. Even after the economic situation stabilised in 2023, the agricultural sector continued to operate in conditions of high costs, which requires further adaptation and state support to ensure the profitability of production.

The agricultural sector of Ukraine has undergone significant changes in tax policy and state support, which was the result of the need to adapt to economic challenges and instability. In 2021, agricultural producers worked under preferential taxation with a value-added tax rate of 20%, which provided budget revenues of UAH 60.7 billion. State support amounted to UAH 3.8 billion aimed at reimbursement of value-added tax, subsidies, and lending programmes, which contributed to the development of the industry and support for producers (Decision of the..., 2024). In 2022, the situation became more complicated due to the war. Although the value-added tax rate remained unchanged, farmers received benefits such as single tax exemptions and deferred tax payments. This allowed partially easing financial pressure, but tax revenues to the budget were reduced to UAH 45.8 billion. State support also decreased to UAH 2.5 billion, although the focus remained on reimbursement of value-added tax and direct subsidies, which helped farmers to maintain their activities in difficult conditions. In 2023, there were drastic changes aimed at stabilising and developing the

agricultural sector. The introduction of the minimum tax burden mechanism allowed legalising about 11 million hectares of agricultural land, providing additional revenues in the amount of UAH 1,500 per hectare. The volume of state support increased to UAH 10.5 billion, which was a significant step forward compared to previous years. Total tax revenues from the sector increased to UAH 52.8 billion, reflecting the positive impact of the new measures. Such changes have become important for ensuring the financial stability of the agricultural sector, supporting its legalisation and creating conditions for further development (Dovgal *et al.*, 2017; Ministry of Economy of Ukraine, 2020).

Analysis using a regression model to predict wheat yield in the Dnipropetrovsk Oblast for the next 5 years, considering the annual increase in fuel prices by 10%, the projected wheat yield (cwt/ha) for the period 2021-2023 was calculated based on equation (2): $\beta_0 = 55.2$ (constant); $\beta_1 = 0.2$ (impact of fuel prices); $\beta_2 = 0.3$ (impact of inflation) if β_0 (constant): the base value of the yield if X_1 and X_2 equal to β_1 for each additional 1 UAH/l increase in the fuel price, the yield decreases by 0.2 cwt/ha. β_2 for each 1% increase in inflation, the yield decreases by 0.3 cwt/ha. Fuel prices at the beginning of 2024 were 55 UAH/l. Considering the trends of previous years, growth of 10% was projected annually:

- in 2025: $60.5 \cdot 1.1 = 66.55$ UAH/l;
- in 2026: $66.55 \cdot 1.1 = 73.205$ UAH/l;
- in 2027: $73.205 \cdot 1.1 = 80.5255$ UAH/l;
- in 2028: $80.5255 \cdot 1.1 = 88.57805$ UAH/l;
- in 2029: $88.57805 \cdot 1.1 = 97.435855$ UAH/l.

A stable forecast for fuel price growth of 5% has been adopted, as this estimate considers a gradual decrease in inflationary pressure, stabilisation of energy prices, and the absence of significant factors that could cause sharp fluctuations:

$$Y = 55.2 - 0.2X_1 - 0.3X_2; \quad (8)$$

1. 2024: $Y = 55.2 - 0.2 \cdot 60.5 - 0.3 \cdot 5 = 55.2 - 12.1 - 1.5 = 41.6$ cwt/ha.

2. 2025: $Y = 55.2 - 0.2 \cdot 66.55 - 0.3 \cdot 5 = 55.2 - 13.31 - 1.5 = 40.39$ cwt/ha.

3. 2026: $Y = 55.2 - 0.2 \cdot 73.205 - 0.3 \cdot 5 = 55.2 - 14.641 - 1.5 = 39.059$ cwt/ha.

4. 2027: $Y = 55.2 - 0.2 \cdot 80.5255 - 0.3 \cdot 5 = 55.2 - 16.1051 - 1.5 = 37.5949$ cwt/ha.

5. 2028: $Y = 55.2 - 0.2 \cdot 88.57805 - 0.3 \cdot 5 = 55.2 - 17.71561 - 1.5 = 36.08439$ cwt/ha.

Calculations show that the wheat yield in the Dnipropetrovsk Oblast is gradually decreasing from 41.6 cwt/ha in 2024 to 36.08 cwt/ha in 2028, which indicates a significant impact of the increase in fuel costs on the productivity of the agricultural sector. Based on equation (3), the average value of wheat yield in the Dnipropetrovsk Oblast in future years was calculated:

$$Average = \frac{41.6+40.39+39.059+37.5949+36.0839}{5} = 38.94 \text{ cwt/ha}. \quad (9)$$

The results of the forecast show that the increase in fuel prices by 10% annually has a significant impact on the average wheat yield in the Dnipropetrovsk Oblast. The yield is gradually decreasing from 41.6 cwt/ha in 2024 to 36.08 cwt/ha in 2028, with an average of 38.95 cwt/ha for this period. This dynamic is conditioned by an increase in production costs, which directly affects the economic efficiency of agricultural activities. To stabilise yields in the face of rising fuel prices, innovative approaches to reducing production costs, introducing energy-efficient technologies and state support are needed, in particular, through cost compensation mechanisms and stimulating the use of alternative energy sources (Golub *et al.*, 2020). Scenario analysis is an important tool for assessing the possible performance of the agricultural sector in conditions of economic instability. Its goal is to model various situations based on variable economic factors, such as agricultural prices, yields, crop area, and access to government support.

For the Dnipropetrovsk Oblast, which is one of the leading regions in the production of grain crops, in particular wheat, scenario analysis allows assessing the impact of changes in market conditions on farm incomes. The calculations were based on the average yield, the area of agricultural land, and the selling price of products. Three scenarios – optimistic, baseline, and pessimistic – allow understanding the possible risks and prospects for the development of the industry, depending on economic conditions. The prospects for the development of the industry depend on economic conditions. Given that the area of agricultural land is 104,756 hectares, and the wheat yield is 45 cwt/ha, the estimate of potential income varies depending on price scenarios. In the baseline scenario, at a sales price of UAH 8,000/t, a stable level of income is expected. In the case of an optimistic scenario, in which the selling price increases by 10% and amounts to UAH 8,800/t, a significant increase in profit is possible. But a pessimistic scenario, which provides for a 10% reduction in the price to UAH 7,200/t, can significantly reduce the yield, emphasising the dependence of economic indicators on market conditions. An optimistic scenario: it provides for an increase in state support, access to soft loans and improved market conditions, which increases the selling price to UAH 8,800/t. Data on the amount of additional potential for 3 scenarios were calculated based on equation (4):

$$D_{wholesale} = 45 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 8{,}800 \text{ UAH/t} = 41{,}902{,}608 \text{ UAH}. \quad (10)$$

Baseline scenario. Maintaining the current economic situation unchanged. Sales price remains at the level of 8,000 UAH/t:

$$D_{basic} = 45 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 8{,}000 \text{ UAH/t} = 38{,}012{,}160 \text{ UAH}. \quad (11)$$

Pessimistic scenario It is expected to further increase costs due to inflation and higher fuel prices, which reduces the selling price to UAH 7,200/t:

$$D_{pessimistic} = 45 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 7{,}200 \text{ UAH/t} = 34{,}210{,}944 \text{ UAH}. \quad (12)$$

Scenario analysis of the profitability of the agricultural sector of the Dnipropetrovsk Oblast demonstrated the

importance of considering changes in economic conditions for predicting the results of economic activity. In an optimistic scenario, which provides for increased state support and stability of market prices, income from wheat cultivation on an area of 104,756 hectares may increase significantly, creating favourable conditions for further development of farms. The baseline scenario, characterised by maintaining the current state, reflects stable but limited returns without significant improvements or risks. The pessimistic scenario, which considers the negative impact of inflation and rising costs, showed a significant decline in revenues, which could jeopardise the profitability of production.

Thus, the results of the analysis indicate the need to introduce effective mechanisms of state support, such as subsidies and concessional lending, to mitigate the impact of negative factors and stimulate the growth of the agricultural sector. This will ensure the stability of farm incomes and increase their competitiveness even in unfavourable conditions. The study will conduct an analysis for sunflower, considering the following data: the area of land – 104.756 ha, the yield – 26.3 cwt/ha, and the base selling price – 23,700 UAH/t. For the optimistic scenario, it is planned to increase the selling price by 10%, which is 26,070 UAH/t, and for the pessimistic scenario – a decrease in the price by 10%, to 21,330 UAH/t. Calculations of these indicators are based on equation (4), which determines the additional income potential by multiplying the yield, crop area, and selling price of products:

$$D_{wholesale} = 26.3 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 26{,}070 \text{ UAH/t} = \\ = 71{,}998{,}554 \text{ UAH.} \quad (13)$$

$$D_{basic} = 26.3 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 23{,}700 \text{ UAH/t} = \\ = 65{,}453{,}772 \text{ UAH.} \quad (14)$$

$$D_{pessimistic} = 26.3 \text{ cwt/ha} \cdot 104{,}756 \text{ ha} \cdot 21{,}330 \text{ UAH/t} = \\ = 58{,}909{,}033 \text{ UAH.} \quad (15)$$

The results of the analysis showed that the income from growing sunflower seeds on an area of 104,756 hectares significantly depends on fluctuations in sales prices. The optimistic scenario, which provides for an increase in the selling price to 26,070 UAH/t, will provide an income of UAH 71,998,554, which is the most profitable option for farmers. In the baseline scenario, if the sales price level is maintained at 23,700 UAH/t, the income will amount to UAH 65,453,772. The least favourable scenario is a pessimistic one, in which the selling price will decrease to 21,330 UAH/t, which will lead to a reduction in income to UAH 58,909,033. These results demonstrate a significant impact of economic conditions on the financial stability of the agricultural sector. To minimise risks, it is recommended to diversify activities, use insurance mechanisms to protect income, and introduce effective agricultural technologies.

To adapt the agricultural sector of the Dnipropetrovsk Oblast to the current challenges caused by economic instability, it is important to implement comprehensive strategies aimed at improving production efficiency, reducing costs, and minimising risks. The first step should be to diversify crops. Increase the area under oilseeds such as sunflower and rapeseed. In 2023, the average sunflower yield in the region was 26.3 cwt/ha. If the area of sunflower crops is increased by 20% of the total area of cultivated land of 104,756 hectares, this can provide an additional yield of 5,505. tons. With an average selling price of 12,000 UAH/t, this will provide an additional income of UAH 66 million. This approach will not only increase profitability, but also reduce dependence on monocultural production, which is vulnerable to price fluctuations.

The second important measure is the use of local fertilisers to reduce dependence on imports. In 2022, the cost of imported fertilisers increased by more than 30%, which significantly increased the cost of production. If farmers switch to using local fertilisers, the cost of which is 20-25% lower than imported analogues, this will save about 400 UAH/ha on fertilisers. On an area of 104,756 hectares, this will provide a total savings of UAH 41.9 million in one season. The saved funds can be used to modernise equipment or purchase high-quality seeds.

The third key step should be the introduction of crop insurance. In 2022, farmers of the region lost about 20% of their crops due to adverse weather conditions and fighting. The introduction of crop insurance with coverage of at least 70% of losses will allow farmers to compensate for losses. For example, wheat insurance with an average yield of 50 cwt/ha and a price of 8,000 UAH/t on an area of 50 hectares will cost approximately UAH 20,000 per season, but in case of complete loss of the crop, it will provide compensation up to UAH 280,000. Such a mechanism will increase the financial stability of farms and reduce the risks of bankruptcy.

Additionally, it is worth considering the introduction of modern technologies, such as precision farming systems, that can optimise the use of resources and increase yields. For example, the use of drones to monitor the condition of crops can reduce the cost of processing fields with chemicals by 10%, which for an area with an average crop area of more than 100 hectares will provide savings of UAH 100-120 thousand per season. Thus, the comprehensive implementation of the proposed strategies will increase the economic stability of the agricultural sector of the Dnipropetrovsk Oblast. The use of local fertilisers, crop diversification, and crop insurance combined with modern technologies will contribute not only to reducing costs, but also to increasing profitability, ensuring the sustainable development of the agricultural sector even in difficult economic conditions.

The results of the analysis of acreage and yield of the main crops in the Dnipropetrovsk Oblast for 2021-2023 show a significant impact of economic and social challenges on the agricultural sector of the region. During this period, fluctuations in the structure of crops of the main crops were observed. The area under winter wheat was gradually reduced, which may indicate a change in the priorities of farmers. Sunflower and rapeseed showed an increase in acreage, confirming their economic attractiveness in conditions of instability. Despite the challenges, the yield of key crops remained stable, and in some cases even showed a recovery, which underscores the sustainability of the agricultural sector. However, to ensure long-term growth and sustainability of the regional agricultural

sector, new approaches to management are needed, in particular, crop diversification, introduction of innovative technologies, and active state support.

▸ Discussion

The agricultural sector plays a key role in ensuring food security and economic stability, especially in the face of global challenges. Analysis of the impact of economic, environmental, and social factors on the development of agriculture allows identifying the main mechanisms for improving its sustainability and efficiency. The use of quantitative methods, such as modelling and regression analysis, helps to identify the relationships between key indicators and develop recommendations for sustainable development of the agricultural sector in various regional and international contexts.

The current study and the paper by Q. Yang *et al.* (2022) share common features and differences due to geographical and contextual conditions. Both focus on the sustainability of the agricultural sector, but with different accents. This study examined the impact of economic instability on the agricultural sector of Dnipropetrovsk Oblast, while Q. Yang *et al.* analysed the impact of fluctuations in international prices on China's agricultural regions. The analysis of the spatial and temporal dynamics of change and the role of public policy in strengthening sustainability is a common feature. This study highlights the importance of public investment, and Q. Yang *et al.* – effectiveness of the policy of minimum purchase prices and subsidies in China. Comparison with the paper by F.S. Xolmurotov *et al.* (2024) identified common features and differences. Both studies focus on the role of agriculture in shaping the economic sustainability of regions. F.S. Xolmurotov *et al.* analysed in detail the impact of agriculture on gross domestic product, employment, income, and export potential, offering a universal approach that considers the relationship with industry and services. But the current study focuses on local features of the agricultural sector in Ukraine.

The current study and the paper by K. Kuipers *et al.* (2024) have common features and differences due to different approaches. K. Kuipers *et al.* focused on the political evolution of sustainable development in the province of Flevoland (Netherlands), including environmental, economic, and social aspects. This study analysed the economic indicators of 2021-2023, while K. Kuipers *et al.* conducted a long-term analysis (1986-2022) using interviews and policy documents. The environmental aspect in this study was related to attracting foreign investment, whereas K. Kuipers *et al.* emphasised changing political rhetoric. Social component in K. Kuipers *et al.* was limited to supporting agribusiness, whereas in this study it was considered through investment. K. Kuipers *et al.* focused on the difficulties of implementing the policy, and this study focused more on the results of the recovery of the agricultural sector.

Both the current study and V. Stehel *et al.* (2019) shared common features and differences that reflect different approaches to the analysis of the agricultural sector. Both studies focused on assessing the sustainability of agricultural enterprises. The general focus was on the economic sustainability of the agricultural sector. V. Stehel *et al.* used cluster analysis based on neural networks to evaluate 4,201 agricultural enterprises in the Czech Republic. The results of both studies confirmed the importance of investment for improving agricultural efficiency, although the scope of the analysis varied: the current study focused on the regional level, while V. Stehel *et al.* covered the national context.

F.U. Khan *et al.* (2024) examined financial constraints in agriculture in developing countries, focusing on barriers such as high rates, difficult credit conditions, and lack of infrastructure. Both studies recognised the importance of financial support and investment in improving the productivity of the agricultural sector. F.U. Khan *et al.* focused on global systemic problems, while this study focused on the impact of investment on the economy of Dnipropetrovsk Oblast. The difference was the scale of the analysis: F.U. Khan *et al.* investigated the global context, and the current study examined the local challenges of the region.

T.V. Kalashnikova *et al.* (2019) highlighted common aspects of the analysis of investment support in the agricultural sector and its impact on agricultural development, but there were also significant differences in research areas and accents. Both studies highlighted the importance of investment to improve agricultural productivity. T.V. Kalashnikova *et al.* explored investment security through a multi-factor approach, considering the impact of profitability, lending, government support and foreign direct investment on gross value added. Both studies also emphasised the importance of forecasting the development of the agricultural sector. T.V. Kalashnikova *et al.* offered forecasts based on optimistic, realistic, and pessimistic scenarios for the development of agriculture in Ukraine.

C. Harkness *et al.* (2023) and R. Berry *et al.* (2022) examined aspects of the stability and economic sustainability of agriculture in England and Wales. C. Harkness *et al.* analysed the impact of climate change, management practices and government subsidies on the stability of the agricultural sector in 2005-2017, emphasising the importance of adapting solutions to climatic conditions. Diversification, efficient use of agrochemical resources, and agroecological management were identified as the main factors of stability. R. Berry *et al.* created an agricultural sustainability index based on spatial analysis, considering financial stability, economic efficiency, income diversification, and crop diversity. Both studies approached sustainability analysis through multidimensional metrics. C. Harkness *et al.* focused on management and climate aspects, while R. Berry *et al.* emphasised financial stability and used a geographical approach to visualise sustainability by region. The main difference was in the scale: C. Harkness *et al.* analysed multidimensional aspects of management, whereas R. Berry *et al.* focused on the subnational level through spatial analysis. Both approaches are useful for understanding the stability of the agricultural sector in the face of changes.

Both the current study and the paper by I. Rumyk *et al.* (2021) analysed the financial aspects of supporting and forecasting the development of the agricultural sector, but each of them had its own unique features that reflect different accents in the approaches. Common to both

studies was the emphasis on the role of financial support in the development of the agricultural sector. I. Rumyk *et al.* emphasised that an effective financing system provides for the optimal use and distribution of various sources of funding. The study by I. Rumyk *et al.* applied economic and mathematical modelling to assess the impact of investment on food production, in particular, the Statgraphics software suite was used to build forecasts. Instead, I. Rumyk *et al.* considered long-term forecasts of food security until 2030, using multi-factor models to estimate agricultural production per capita.

The study by I.-M. Gren *et al.* (2024) analysed the economic impact of trade barriers in Sweden, including the impact of reduced imports on food self-sufficiency, accessibility for low-income households, and the well-being of producers and consumers. The paper addressed the international context, while the present study focused on investments within the region. I.-M. Gren *et al.* used a multi-factor approach to food availability, and the current study focused on economic indicators. A.Y. Hassan & M.A. Mohamed (2024) analysed the impact of economic and environmental factors on agricultural productivity in Somalia using the Autoregressive Distributed Lag model. Investment and rural population growth have a positive impact on productivity, while CO_2 emissions had a negative effect. A common approach was to assess the role of investment in productivity and consider environmental factors such as precipitation. A.Y. Hassan & M.A. Mohamed evaluated short- and long-term effects, while the current study focused on the regional impact of investment.

V. Georgieva *et al.* (2024) examined the impact of ammonia emissions, organic farming, and production costs on soft wheat prices in France, Germany, Italy, and Spain (2000-2022). The emphasis was placed on the analysis of environmental factors and price stability. The common features with the current study were the attention to the role of economic and environmental factors in the development of the agricultural sector and the use of quantitative analysis. Main differences: V. Georgieva *et al.* covered several EU countries and regional differences in the impact of environmental indicators, while the current study focused on investment and climate conditions in a particular region.

The study by M. Dziamulych *et al.* (2022) predicted the economic performance of agricultural enterprises in Ukraine using the "AGMEMOD-Ukraine" model, considering demographic changes, state support, and production costs. Common features were the emphasis on sustainable development of the agricultural sector and the use of multi-factor models for investment and cost analysis. The difference was in the focus: M. Dziamulych *et al.* focused on economic aspects and long-term forecasts until 2030, while this study focused more on environmental factors such as climate conditions and precipitation.

The study by M. Swain (2014) examined the impact of rain instability, irrigation infrastructure, and fertilisers on yields in Western Odisha, India, where low irrigation coverage and rain dependence were key issues. Together with the current study, the impact of climate on agriculture and the importance of sustainable resource management were highlighted. M. Swain analysed regional issues such as droughts and infrastructure deficiencies, while the current study covered broader geographical and integrated aspects of economic and environmental factors.

Y. Lopatynskyi *et al.* (2021) analysed the scenarios of transformation of the institutional environment of the agricultural sector of Ukraine through the concept of sustainable development. The researchers proposed forecasting scenarios (pessimistic, realistic, optimistic), focusing on the integration of economic, social, environmental, and institutional components. Common to this study were the emphasis on the concept of sustainable development, scenario analysis, and the importance of a balanced approach. The difference is that Y. Lopatynskyi *et al.* focused on the long-term transformation of Ukraine's institutional environment using an interdisciplinary approach, while the current study focused on quantitative analysis of investment and climate change. Both approaches complement each other, offering different perspectives for analysing the sustainability of the agricultural sector.

The study by S. Gazuda *et al.* (2024) analysed regional features of agricultural development and its significance for the economy, which coincides with the subject of the current study. Common emphasis was placed on the importance of the agricultural sector for economic stability and the use of quantitative analysis of the impact of agriculture on regional development. The current study focused on the Dnipropetrovsk Oblast, while S. Gazuda *et al.* covered a broader international context, emphasising innovative technologies and government support, which were covered in less detail in this paper.

E. Régnier & A. Catallo (2024) examined the challenges and opportunities of Ukraine's potential accession to the EU, with a focus on reforming agriculture in accordance with the requirements of the common market. Common features were the emphasis on sustainable development of the agricultural sector, the impact of institutional reforms, and the importance of foreign economic relations. The current study focused on internal aspects of regional development and quantitative analysis, whereas E. Régnier & A. Catallo focused on the international dimension and cooperation between Ukraine and the EU.

R.V. Ivanov & Y.V. Hurtovyi (2023) analysed the impact of foreign economic activity of the agricultural sector on the economic security of Ukraine, in particular, export-import balances and the impact of military operations on prices. There was a common emphasis on the role of exports in building economic resilience. However, R.V. Ivanov & Y.V. Hurtovyi focused more on the foreign economic context and challenges of war, while the current study highlighted the long-term investment attractiveness of the agricultural sector.

A.T. Kinkpe *et al.* (2024) investigated the impact of the food industry on Benin's economy, focusing on added value through cashew and pineapple processing. Both studies recognised the importance of agricultural value chains and government support in stimulating development. A.T. Kinkpe *et al.* analysed the African economy using CGE modelling, while the current study focused on the impact of economic changes on the agricultural sector of Ukraine and its integration into the European market.

Analysis of the agricultural sector confirms its strategic importance for ensuring food security and economic

sustainability. The use of modern research methods helped to better understand the impact of economic, environmental, and social factors on the development of agriculture. The results of the study show that to achieve sustainable and balanced development in the agricultural sector, an integrated approach is needed, which includes investment support, the introduction of innovative technologies, and adaptation to changing conditions.

▸ Conclusions

The findings of this study highlighted the key role of the agricultural sector in the economic development of the Dnipropetrovsk Oblast in the context of economic instability caused by military operations and macroeconomic challenges. In 2021, gross agricultural output amounted to UAH 41.6 billion, but in 2022 this figure fell to UAH 27.5 billion, which reflects the serious economic consequences of the war. In 2023, there was a partial recovery, and gross output reached the level of UAH 32.5 billion, which, however, was below the pre-war level. Investment dynamics have also undergone significant changes. In 2021, the total volume of investments in the agricultural sector amounted to about UAH 8.5 billion, of which 20% accounted for state investments, 15% – for foreign investments, and 65% were provided by private sources. In 2022, due to difficult economic conditions, the total volume of investment decreased to UAH 5.2 billion, although the share of public investment increased to 25%, which indicates active support from the government. In 2023, the total volume of investments increased to UAH 6 billion due to the restoration of confidence of foreign investors (15%) and the adaptation of the private sector (60%).

A deeper analysis showed that the gross regional product in 2022 decreased to UAH 313.83 million (compared to UAH 582.36 million in 2021) had a significant impact on the economic stability of the region. The partial recovery in 2023 to UAH 398.73 million indicates the adaptation of the agricultural sector to new challenges. A significant factor in stabilisation was public investment, which contributed to the modernisation of production infrastructure and support of production processes. To predict wheat yields, this study used a regression model, where the dependent variable was yield, and the independent variables were fuel price and inflation rate. The basic yield was 55.2 cwt/ha, provided that the fuel price – 55 UAH/l, and the inflation rate – 0%. According to the model, each increase in the price of fuel by 1 UAH/l reduced the yield by 0.2 cwt/ha, and each increase in inflation by 1% reduced the yield by 0.3 cwt/ha. Forecasts until 2028 indicated a gradual decline in wheat yields due to rising fuel prices and inflationary impacts. The forecasted yield in 2024 was 54.16 cwt/ha, and in 2028 – 36.08 cwt/ha.

Structural changes in acreage, in particular, an increase in the share of sunflower and rapeseed, indicate a strategic reorientation of farmers to more profitable crops. This helped to partially compensate for losses from reducing the area under grain crops. The recovery of export potential in 2023 also indicated the stabilisation of logistics chains, which were significantly disrupted in 2022. The results of the study show that in order to ensure the long-term sustainability of the agricultural sector, it is necessary to expand investment programmes, stimulate the private sector, and attract foreign investment. Further economic recovery in the region is possible due to the diversification of agricultural production, support for environmentally sustainable agriculture, and expansion of export opportunities. In addition, it is important to ensure the effective use of state resources to support the agricultural sector, which will consolidate positive dynamics and create the basis for stable economic growth in the region.

▸ Acknowledgements

None.

▸ Funding

None.

▸ Conflict of interest

None.

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Прогнозування регіонального розвитку аграрної сфери в умовах економічної нестабільності

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▸ **Анотація.** Метою дослідження було оцінити вплив економічних факторів на аграрний сектор Дніпропетровської області за період 2021-2024 років, визначити ключові тенденції та розробити підходи до підвищення економічної стійкості регіону. У рамках дослідження було застосовано методи регресійного аналізу, економетричного моделювання та сценарного підходу для оцінки динаміки врожайності, структури посівних площ, інвестиційної активності та частки аграрного сектору у валовому регіональному продукті. Результати дослідження показали, що частка аграрного сектору у валовому регіональному продукті коливалася в межах 7,5-8,76 % протягом аналізованого періоду. Найвищий показник у 8,76 % був зафіксований у 2022 році через скорочення загального валового регіонального продукту на 46 % у порівнянні з 2021 роком. Водночас, обсяг виробництва аграрної продукції зменшився на 33,9 % у 2022 році, але частково відновився у 2023 році, досягнувши 32,5 млрд грн. Проведений регресійний аналіз виявив, що зростання ціни на паливо на 1 грн/л знижує врожайність пшениці на 0,2 ц/га, а підвищення рівня інфляції на 1 % призводить до зменшення врожайності на 0,3 ц/га. Сценарний аналіз продемонстрував можливі наслідки змін економічних умов: у песимістичному сценарії врожайність пшениці до 2028 року може знизитися до 36,08 ц/га. Значущість отриманих результатів полягає у можливості їх використання для формування стратегій відновлення та розвитку аграрного сектору в умовах економічної нестабільності. Запропоновано акцентувати увагу на залученні іноземних інвестицій, диверсифікації посівів та впровадженні енергоефективних технологій для підвищення стійкості регіону. Результати дослідження також підкреслюють важливість державної підтримки, яка становила 25 % загальних інвестицій у 2023 році, що сприяло частковому відновленню економічної активності в аграрному секторі

▸ **Ключові слова:** валова продукція; інвестиційна діяльність; диверсифікація культур; страхування врожаїв; структура посівів

ЕКОНОМІКА АПК
Науково-виробничий журнал

Том 32, № 2
2025

Відповідальний редактор:
О. Дендебера

Підписано до друку 13.03.2025
Формат 60*84/8
Ум. друк. арк. 14,9
Наклад 100 прим.

Видавництво: Національний науковий центр «Інститут аграрної економіки»
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EKONOMIKA APK
Scientific and Production Journal

Volume 32, No. 2
2025

Managing Editor:
O. Dendebera

Signed to the print 13.03.2025
Format 60*84/8
Conventional Printed Sheet 14.9
Circulation 100 copies

Publisher: National Scientific Centre “Institute of Agrarian Economics”
03127, 10 Heroiv Oborony Str., Kyiv, Ukraine
Tel.: (+38044)258-43-21
E-mail: info@eapk.com.ua
https://eapk.com.ua/en