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Employment of the rural population in Ukraine: Qualitative and quantitative dimensions

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► **Abstract.** The rural labour market in Ukraine has undergone significant transformations due to shifts in the role and format of the agricultural sector's impact on rural development, the administrative-territorial reform and decentralisation processes, and the full-scale aggression by the Russian Federation. The objective of this study was to assess the impact of key factors on rural employment in Ukraine and to identify principal directions for increasing its level. The research was grounded in a systems approach. Analytical tools included comparative analysis, averages and relative values method, graphical analysis, trend analysis, index analysis, correlation-regression analysis (multifactor model), etc. Employment trends among the rural population in Ukraine from 2000 to 2023 were examined. It was found that since 2013, the employment rate among the working-age rural population has exhibited a downward trend. The study identified key issues and specific characteristics of rural employment under current conditions. An econometric model of rural employment among the working-age population was developed, revealing its direct dependence on real gross domestic product, the number of unemployed persons undergoing vocational training, and wage levels. A negative influence on rural employment was found to be exerted by increased investment volumes and the number of enterprises, attributed to higher technological intensity, the emergence of new employment forms, consolidation and restructuring of employment, and ongoing military actions. The article outlined priority measures for enhancing rural employment. The key findings, quantitative assessments, proposals, and conclusions might be utilised by public authorities in revising existing policies and developing new strategic programmes on rural employment, considering current challenges, internal risks, and the protracted Russian-Ukrainian war

► **Keywords:** rural labour market; influencing factors; econometric modelling; challenges; priorities

► Introduction

Assessing the specifics of rural development in Ukraine from 2000 to 2024 reveals a range of pressing economic, social, and demographic challenges. These are largely the result of systemic neglect of rural living and working conditions at the national, regional, and local governance levels, compounded in recent years by the impact of ongoing military hostilities. Given that rural areas form the foundation of the country's agro-industrial complex

and their residents represent the core of Ukrainian identity, there is every reason to assert that these issues pose a threat not only to rural territories themselves but also to the country's overall socio-economic development and economic security. One of the most critical issues in Ukraine's rural areas, directly affecting the well-being and quality of life of the rural population, is the persistently low employment rate and growing unemployment.

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Between 2014 and 2023, nearly half of rural residents were either unemployed or engaged in the informal sector. This underscores the urgency of research aimed at assessing the state of rural employment, identifying its key drivers, evaluating their impact, and developing solutions (State Statistics Service of Ukraine, n.d.).

According to V. Kostrytsia & T. Burlay (2020), the main drivers of imbalances in Ukraine's labour market include globalisation, digitalisation, demographic shifts, and migration. In the context of European integration and the need to mitigate negative labour market trends, they emphasise the importance of adopting new labour legislation aligned with employee interests and fostering balanced labour relations. They also highlight the need for comprehensive programmes to preserve existing jobs, create new employment opportunities, strengthen the institutional capacity of the state employment service, and improve the national wage system.

Although, as noted by M. Dziamulych & S. Maksymyak (2023), economic activity among the rural population remains relatively high, it is primarily concentrated in personal subsistence farming and seasonal work abroad. These researchers therefore argue for prioritising the development of comprehensive support programmes for entrepreneurship in the agricultural sector to ensure formal employment for rural residents. Similarly, O. Borodina *et al.* (2025) stress the importance of formalising rural employment as a key factor in rural development. They propose distinguishing between the terms, "farmer" and "active farmer", introducing their legal definitions, and implementing them in practice.

In their study, N. Patyka & O. Mohylnyi (2023) highlight the mismatch between the education and acquired competencies of rural residents and the demands of enterprises in the agricultural sector of the economy. This highlights the need for transformation within the vocational agricultural education system. Another problematic aspect of rural employment is identified by S. Kalinina & S. Lanska (2019), who underline the limited availability of non-agricultural employment opportunities in rural areas. They attribute this largely to systemic deficiencies in training specialists for the agricultural sector. According to O. Ubi Ubi & O.R. Bernard (2024), a significant cause of rural unemployment is insufficient or inefficient funding for rural development, coupled with corruption in the distribution of public financial resources.

Despite a growing body of academic research, further in-depth studies are required to identify and quantify the factors affecting rural employment in Ukraine. A thorough analysis of these factors and an assessment of their impact are particularly relevant, as this is essential for the development of effective state policies aimed at increasing rural employment in the country. Accordingly, the purpose of this study was to identify the factors influencing the level of rural employment in Ukraine, quantify the influence of selected variables, and propose measures to enhance employment levels. To achieve the stated purpose, the following tasks were set: to monitor rural employment in Ukraine and identify the factors influencing its level; to quantitatively assess the impact of selected factors on the level of rural employment; and to substantiate priority directions for increasing rural employment.

► Materials and methods

The study employed the dialectical method of scientific inquiry along with general scientific and specific research methods. In particular, economic and statistical methods (comparative analysis, mean and relative values, trend analysis, graphical method, index analysis, etc.) were applied in analytical studies to assess the status, trends, and characteristic features of rural employment. System analysis was used to identify the factors influencing rural employment. Using techniques of the abstract-logical method and the method of generalisation, conclusions were formulated, and priority directions for ensuring rural employment were determined. Economic and mathematical modelling of rural employment levels was conducted using the least squares method to construct a regression equation over the entire time interval of the collected relevant data. The study utilised official statistical data from the State Statistics Service of Ukraine (n.d.), the State Employment Service (n.d.) from 2000 to 2023, the World Economic Forum (n.d.), the World Bank Group (n.d.), and the authors' calculations.

The collection of statistical information and database formation included the following indicators: employment rate of the rural population, including by age groups; employment structure by types of economic activity; number of working-age rural residents; real GDP; volume of investment in agriculture; number of people employed in agriculture; number of hired workers in agriculture; number of formerly unemployed rural residents who found employment; number of unemployed rural residents who received vocational training; number of agricultural enterprises; average monthly wage of the rural population; demand for agricultural workers; number of registered unemployed among rural residents; volume of agricultural production; structure of agricultural output; inflation rate; volume of foreign trade; and other macroeconomic factors. In total, the influence of 27 indicators was analysed.

To account for the influence of institutional factors, government policy in the rural labour market, and the behaviour of labour market participants, both in terms of labour supply and demand, the Labour Market Efficiency Index was included in the calculations. This index is assessed by the World Economic Forum (n.d.) for ranking countries within the Global Competitiveness Index, which has been calculated since 1979. The index incorporates several indicators, including cooperation in labour-employer relations, wage flexibility, hiring and firing practices, the effect of taxation on work incentives, female participation in the labour force, and employment rigidity. At the initial stage, correlation-regression analysis was used to identify relationships between individual factors. For further research and model construction, only statistically significant influencing factors were used. Modelling was carried out using the EVIEWS econometric software package.

► Results and discussion

Economic science encompasses numerous employment theories that address the factors influencing employment. These range from classical approaches (neoclassical, neoliberal, rational expectations theory), which advocate for full employment and minimal government intervention in the market processes; to Keynesian doctrines (neo-Keynesian, economic growth theory, business cycle

theory), whose proponents consider unemployment a natural market phenomenon and argue for the state's regulatory role under specific conditions such as economic crises; to modern concepts that view employment as a means to generate and grow income for investment in human capital, as a prerequisite for improving the quality of human capital (human capital theory), as a condition for redistributing the benefits of economic growth among population groups (basic needs concept), or as a means to realise human potential (human development concept).

Given the current state of Ukraine's economy and its rural areas, in particular, it is not feasible to rely solely on a single employment theory when studying rural employment. Such analysis must be grounded in a synthesis of various theories, including Keynesian theory, economic growth theory, and the human development concept. Summarising the results of the analysis of modern theoretical foundations for studying rural employment and the mechanisms for its support, it becomes evident that this issue is not limited to the economic dimension alone. It also requires examining the current institutional framework for rural employment in Ukraine and the broader socio-economic development of rural areas. This will eventually enable the formulation of a market-relevant organisational and economic mechanism to support rural employment in Ukraine, define its structural components, and outline the priorities for its implementation.

As stated in Article 43, Chapter 2 of the Constitution of Ukraine: "Everyone shall have the right to work, including the opportunity to earn a living by work which he or she freely chooses or to which he or she freely agrees." To this end, "the state shall create conditions for the full realisation by citizens of the right to work, guarantee equal opportunities in the choice of profession and type of labour activity, and implement vocational training, education, and retraining programmes under societal needs" (Constitution of Ukraine, 1996). However, the reality tells a different story. According to employment monitoring of the working-age rural population in 2021 (based on official data from the State Statistics Service of Ukraine (n.d.)), the employment rate for this age group dropped by 9.9 percentage points to 53.6% compared to 2013, which recorded the highest level of 63.5% during 2000-2021. The assessment of rural employment levels during the wartime years of 2022-2023 showed a continued downward trend, reaching 50.2% in 2023 (Fig. 1). This means that only slightly more than half of the working-age rural population is employed. This situation in the rural labour market has been driven by numerous destructive factors: socio-demographic, economic, institutional, political, and individual (Patyka *et al.*, 2021). In 2022-2024, additional factors emerged as a result of the full-scale Russian aggression against the Ukrainian people. The summarised current issues of rural employment are visualised in Figure 2.

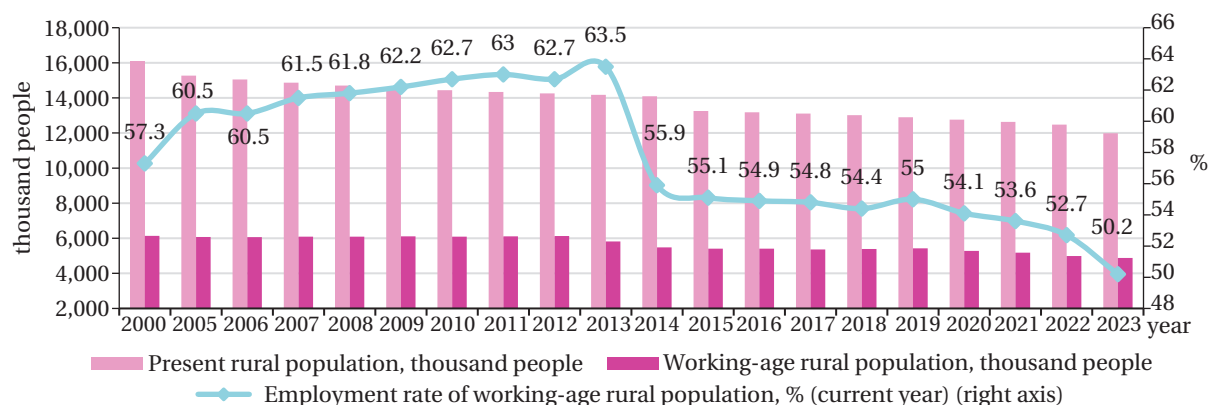


Figure 1. Employment of the rural working-age population

Notes: 2022-2023 – authors' estimates

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

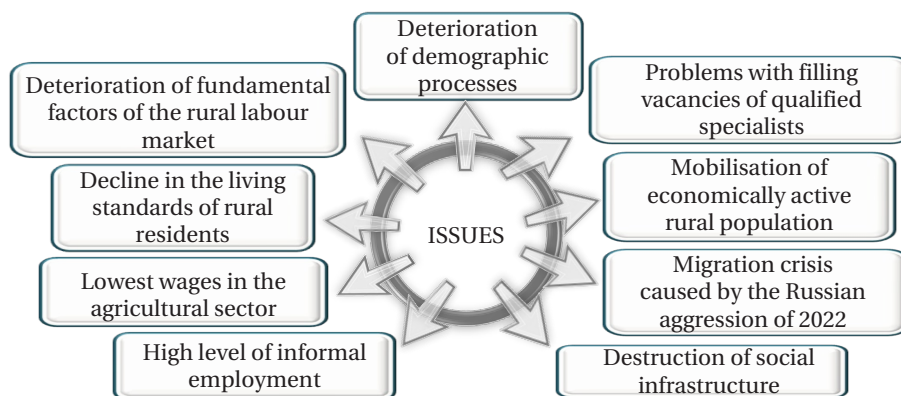


Figure 2. Issues of rural employment in Ukraine

Source: compiled by the authors based on the results of their own research

It is worth noting that the employment rate of the rural population continues to decline even amid a reduction in the working-age population residing in rural areas – and at an even faster pace. Specifically, between 2000 and 2021, the number of employed individuals aged from 15 to 70 decreased by 24.8%, from 6.429 million in 2000 to 4.835 million in 2021. At the same time, the total rural population within this age group declined by 19.2%, from 11.216 to 9.062 million respectively. The highest employment rate is recorded among the rural population aged 35-49,

exceeding 72%, and slightly lower, around 70%, among those aged 30-34. However, among the seven age groups analysed, only one group (50-59 years) saw an increase in employment: by 5.2 percentage points during 2000-2021. The most vulnerable to job loss were rural residents aged 25-29 (-11.7 p.p.), 60-70 (-10.3 p.p.), 40-49 (-8.5 p.p.), and 35-39 (-8.3 p.p.) years (Table 1). It should also be noted that a distinctive feature of rural areas is that fewer than 70% of all employed individuals are officially registered employees (Table 2). This reflects a high level of informal employment.

Table 1. Employment rate of the rural population aged from 15 to 70 by age group

Year	Age group (years)						
	15-24	25-29	30-34	35-39	40-49	50-59	60-70
2000	36.8	74.8	77.8	81	81.0	60.3	24.7
2005	41.1	71.9	75.9	78.2	78.6	64.8	35.9
2010	42.3	70.9	74.3	77.0	79.5	67.2	41.3
2015	32.3	65.3	67.6	74.7	74.8	60.0	17.3
2016	31.8	65.4	67.5	73.5	74.6	60.0	17.2
2017	31.6	65.3	68.9	72.2	73.9	59.5	16.2
2018	31.6	67.9	70.8	71.9	74.8	61.6	14.2
2019	33.7	68.6	71.1	73.4	75.0	64.6	14.8
2020	28.6	65.6	70.1	70.7	72.6	65.0	14.2
2021	28.7	63.1	69.6	72.7	72.5	65.5	14.4
2021 compared to 2000, p.p.	-8.1	-11.7	-8.2	-8.3	-8.5	5.2	-10.3

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

Table 2. Number of employed persons aged from 15 to 70 in rural areas by employment status

Indicator	2000	2005	2010	2015	2020	2021	2021 compared to 2000
Rural areas, thousand people	6,255.5	6,586.1	6,474.2	5,134.2	4,931.6	4,835.5	77.3%
<i>Including by employment status, as % of total</i>							
employees (paid workers)	78.1	56.5	58.7	68.4	69.5	69.8	-8.3 p.p.
employers	0.2	0.4	0.5	0.9	1.0	1.0	0.8 p.p.
self-employed	18.3	42.0	39.9	30.1	28.9	28.7	10.4 p.p.
unpaid family workers	3.4	1.1	0.9	0.6	0.6	0.5	-2.9 p.p.

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

These indicators reflect the difficult situation in the rural labour market and the significant deterioration of the fundamental factors influencing its functioning, particularly the excess supply of labour compared

to employer demand. Data presented in Table 3 show a substantial reduction in the number of agricultural enterprises and individual entrepreneurs over the period from 2010 to 2022.

Table 3. Number of active enterprises and individual entrepreneurs in agriculture by size

Indicator	Year					2022 compared to 2010, %
	2010	2015	2020	2021	2022	
Large business entities (enterprises)	13	29	36	49	39	300.0
Medium-sized business entities, total	3,445	2,535	2,137	2,095	1,687	49.0
including						
enterprises	3,440	2,533	2,134	2,091	1,683	48.9
individual entrepreneurs	5	2	3	4	4	80.0
Small-sized business entities, total	76,863	76,720	71,195	68,659	51,555	67.1
including						
enterprises	47,213	44,182	47,282	45,613	31,122	65.9
individual entrepreneurs	29,650	32,538	23,913	23,046	20,433	68.9
Of which micro-enterprises, total	72,421	71,649	65,753	63,051	46,622	64.4
including						
enterprises	42,972	39,237	42,042	40,185	26,338	61.3
individual entrepreneurs	29,449	32,412	23,711	22,866	20,284	68.9

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

Only the number of large agricultural producers has increased significantly (threefold). However, large enterprises are vertically integrated and generally do not engage the local rural population in work, nor do they create job opportunities in the local rural labour market. In contrast, the number of medium-sized enterprises decreased by 51%, small enterprises by 32.9%, and micro-enterprises by 35.6%. The reduction in the number of agricultural enterprises, due to various factors both objective and subjective, leads to the elimination or reduction of jobs, and consequently, to a decline in rural employment (Table 4). Despite certain changes in the structure of rural employment by types of economic activity, agriculture continues to hold a leading position among them (Fig. 3). It is logical to assume that even minor changes in the sectoral

structure of the agricultural sphere, production volumes in agriculture, the number of economic entities, and their demand for workers will lead to changes in rural employment. For example, there has been an unprecedented increase in the share of crop production in agricultural production and export. In total agricultural production volumes, crop production accounted for 78.2% in 2022 (compared to 51.5% in 1990), while the share of livestock production decreased by 26.7 percentage points over this period. In 2022, over 77% of those employed in agriculture worked in crop production, 11% in livestock farming, 10.8% in forestry, and less than 1% in fisheries. Information on rural employment by sub-sectors of crop and livestock production and its dynamics comparing 2015 and 2022 is presented in Figure 4.

Table 4. Number of full-time equivalent employees in large-, medium-, small-, and micro-enterprises in agriculture

Year	Employed people, total	Of which hired employees in full-time equivalent	Economic entities							
			large business entities		medium business entities		small business entities		of which micro business entities	
			people	%	people	%	people	%	people	%
2013	726,250	615,615	37,159	6.0	379,383	61.6	199,073	32.3	78,106	12.7
2014	733,384	609,299	43,030	7.1	358,154	58.8	208,115	34.2	73,584	12.1
2016	658,721	551,359	34,526	6.3	329,598	59.8	187,235	34.0	75,197	13.6
2017	635,638	534,351	26,801	5.0	309,838	58.0	197,712	37.0	81,521	15.3
2018	626,072	525,070	31,083	5.9	299,977	57.1	194,010	36.9	80,328	15.3
2019	610,117	515,402	40,893	7.9	279,191	54.2	195,318	37.9	78,701	15.3
2021	576,093	486,364	41,450	8.5	243,897	50.1	201,017	41.3	83,314	17.1
2022	488,555	410,813	33,135	8.1	212,092	51.6	165,586	40.3	64,055	15.6
2023	456,909	379,056	60,793	16.0	163,465	43.1	154,798	40.8	61,888	16.3
2023 compared to 2013	62.9%	61.6%	163.6%	10.0 p.p.	43.1%	-18.5 p.p.	77.8%	8.5 p.p.	79.2%	3.6 p.p.

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

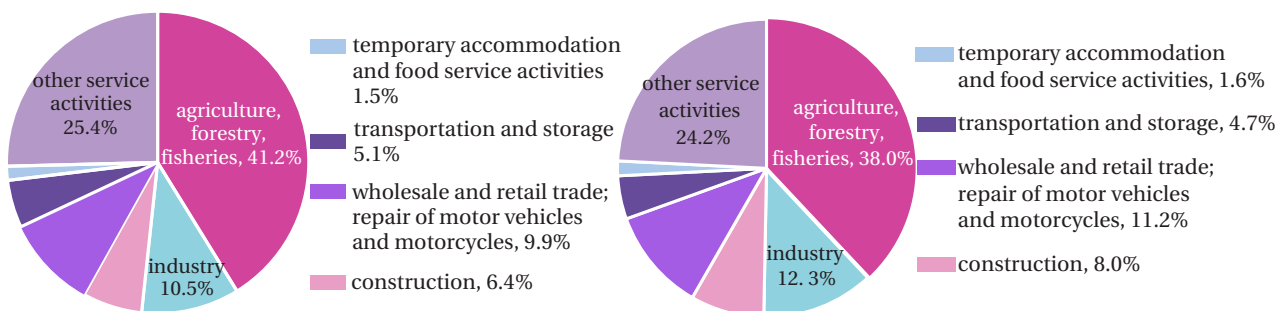


Figure 3. Structure of rural employment by types of economic activity in 2015 and 2022, %

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

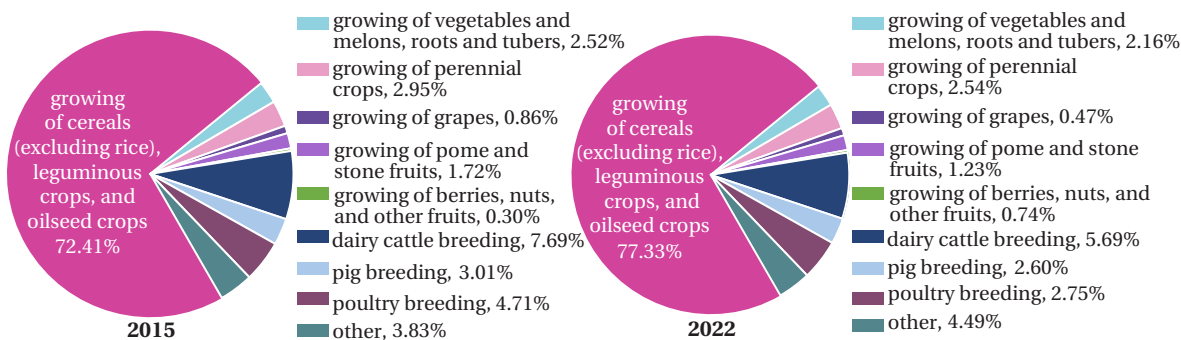


Figure 4. Structure of employed rural population by agricultural subsectors in 2015 and 2022, %

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

Such sectoral disproportions lead to a reduction in labour demand and a decline in employment levels, since crop production, being a less labour-intensive sector, requires significantly fewer workers than livestock farming. To identify the most influential factors affecting rural employment levels

and to assess their impact, economic-mathematical modelling was conducted. Based on the results of correlation-regression analysis and the determination of relationships between individual factors, the model was built using significant influencing factors for the period 2000-2023 (Table 5).

Table 5. Input data for model construction

Year	Employment rate of the rural working-age population, %	Real GDP (2021 = 100), million UAH	Capital investments in agriculture, million UAH	Number of enterprises (including farms) in agriculture, units	Number of unemployed rural population undergoing vocational training, thousand people	Average monthly wage in rural areas, UAH	Labour market efficiency index
	Y	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆
2000	57.3	191,684	496	51,588	66.8	85.42	n/a
2001	60.5	222,451	1,617	54,417	n/a	119.22	n/a
2002	55.9	256,420	1,854.1	61,178	n/a	142.49	n/a
2003	54.7	310,070	2,054	59,923	n/a	165.36	n/a
2004	56.1	368,525	3,381	58,575	n/a	228.61	n/a
2005	60.5	491,951	5,016	57,877	n/a	342.24	n/a
2006	60.5	611,439	7,306	57,858	99.1	452.62	4.21
2007	61.5	767,957	9,519	58,387	111.7	596.17	4.30
2008	61.8	840,844	16,890	59,059	119.4	817.36	4.47
2009	62.2	191,684	9,382	57,152	76.5	914.91	4.57
2010	62.7	949,619	11,062.6	80,321	99.0	1,011.91	4.54
2011	63.0	1,138,338	16,465.9	61,488	105.0	1,195.01	4.44
2012	62.7	1,303,094	18,883.7	68,497	107.7	1,433.46	4.44
2013	63.5	1,404,293	18,587.4	71,058	105.7	1,525.85	4.18
2014	55.9	1,369,190	18,795.6	75,660	96.6	1,535.24	4.12
2015	55.1	1,431,826	30,154.7	79,284	83.9	1,769.86	4.33
2016	54.9	2,037,084	50,484.0	74,620	81.7	1,990.81	4.23
2017	54.8	2,441,661	64,243.3	76,593	80.7	3,178.22	4.01
2018	54.4	3,085,223	66,104.1	76,328	75.1	3,925.13	4.40
2019	55.0	3,674,214	59,129.5	75,450	73.8	5,084.24	4.41
2020	54.1	3,827,941	50,679.7	73,368	52.3	5,314.86	4.40
2021	53.6	4,367,501	69,950.3	70,803	50.7	6,369.16	n/a
2022	52.7	3,883,262	51,439.4	53,281	26.8	7,585.82	n/a
2023	50.2	5,529,085	65,432.1	62,960	14.8	8,873.61	n/a

Source: compiled by the authors based on data from the State Statistics Service of Ukraine (n.d.), State Employment Service (n.d.), World Economic Forum (n.d.), World Bank Group (n.d.)

The inclusion of these indicators and their potential impact on rural employment levels requires explanation. Real GDP is a comprehensive indicator that reflects the result of all processes taking place within a specific sector or the economy as a whole, the effect of developments in other world economies and existing markets on Ukraine's economy, as well as the regulatory influence of the state through the use of various levers and instruments of economic policy. This indicator reflects production efficiency and the level of employee motivation for productive work, enables the assessment of the state and dynamics of changes in economic parameters, and helps identify structural imbalances in its development, among other aspects. Investors consider real GDP, for example, when making decisions about establishing or expanding enterprises. An upward trend in real GDP is likely to enhance the employment rate.

An increase in investment volume can have a dual effect: on one hand, it directly creates new jobs and improves

production efficiency overall: enhancing logistics, building auxiliary facilities, and increasing the workload of existing enterprises, thereby indirectly increasing employment. On the other hand, investments in innovation, scientific and technological research promote automation, robotics, drones, and other technological devices that replace human labour, leading to employment reduction. A similar situation applies to the number of enterprises variable in the model: ideally, growth in the number of enterprises should boost employment, but this is not always the case.

Regarding the rise in the number of unemployed rural residents undergoing vocational training, it is logical to assume a positive impact on rural employment levels. An increase in wages is among the most significant motivating factors for employment growth. However, this effect primarily influences the labour supply side positively. From the employers' perspective, the need to increase wages for regular employees, alongside technological progress, might force layoffs, thus lowering employment levels.

Conversely, increased incomes among the rural population boost their purchasing power, stimulating consumer demand and expanding the quantity and variety of goods and services produced, which in the long term supports employment growth (Krylova *et al.*, 2023).

An increase in the labour market efficiency index implies enhanced production efficiency, which in the short term might reduce employment levels. However, in the long term, the situation may reverse: higher production volumes will increase demand for production factors, including labour, positively impacting employment.

The modelling results produced the following model:

$$Y = 59.0 + 7.33 \cdot \text{LOG}(X_1) - 1.82 \cdot \text{LOG}(X_2) - 12.5 \cdot \text{LOG}(X_3) + 2.21 \cdot \text{LOG}(X_4) + 4.14 \cdot \text{LOG}(X_5) - 4.46 \cdot \text{LOG}(X_6) - 2.76 \cdot \text{dummy14.22} \quad (1)$$

The regression equation demonstrates satisfactory econometric properties (among the tested hypotheses were those related to the normal distribution of residuals, the absence of residual autocorrelation, and the absence of residual heteroscedasticity). The results of the regression analysis are shown in Table 6.

Table 6. Results of regression analysis of selected indicators on rural population employment

Dependent Variable: Y Method: Least Squares Sample (adjusted): 2000-2023 Included observations: 24 after adjustments					
Variable	Coefficient	Std. Error	t-Statistic		Prob.
C	59.03949	43.16905	1.367635		0.3048
LOG(X ₁)	7.334832	4.011859	1.828288		0.2090
LOG(X ₄)	2.213722	1.901768	1.164034		0.3645
LOG(X ₃)	-12.53922	3.833149	-3.271258		0.0821
LOG(X ₅)	4.135394	0.915280	4.518172		0.0457
X ₆	-4.459458	0.850903	-5.240853		0.0345
dummy14.22	-2.763122	0.423627	-6.522540		0.0227
LOG(X ₂)	-1.823113	0.927472	-1.965681		0.1883
R-squared	0.985254	Mean dependent var			70.25000
Adjusted R-squared	0.933644	S.D. dependent var			1.096712
S.E. of regression	0.282509	Akaike info criterion			0.300353
Sum squared resid	0.159623	Schwarz criterion			0.542421
Log likelihood	6.498236	Hannan-Quinn criterion			0.034805
F-statistic	19.09027	Durbin-Watson stat			2.574105
Prob (F-statistic)	0.050666				

Source: compiled by the authors based on the results of their own research

The economic meaning of the dummy variable dummy14.22 is as follows: It reflects a significant decline in the employment rate of the rural working-age population since 2014 (primarily due to the unstable economic situation caused by the armed conflict in the eastern region of the country in 2014) and subsequently the Russian-Ukrainian war in 2022, resulting in a bigger decrease than would be predicted by the model based solely on economic factors. The results showed that modelling the

employment level of the rural population is entirely feasible even with a relatively short time series. As shown in Table 6, the explanatory variables are mostly statistically significant at the 5-10% level, which is acceptable given the short modelling period, and their signs are consistent with economic interpretation (Table 7). The coefficient of determination R² (0.985) signifies that 98.5% of the fluctuations in rural employment rates are attributable to changes in the independent variables.

Table 7. Interpretation of model elasticities

a 1% increase in	real GDP	leads to	a 7.33 p. p.	rise in the employment rate of the working-age rural population
a 1% increase in	investment volume	leads to	a 1.82 p. p.	decrease in the employment rate of the rural working-age population
a 1% increase in	the number of enterprises	leads to	a 12.5 p. p.	decrease in the employment rate of the rural working-age population
a 1% increase in	the number of unemployed persons undergoing vocational training	leads to	a 2.21 p. p.	rise in the employment rate of the working-age rural population
a 1% increase in	rural population incomes	leads to	a 4.14 p. p.	rise in the employment rate of the working-age rural population
a 0.1 increase in	the labour market efficiency index	leads to	a 0.45 p. p.	decrease in the employment rate of the rural working-age population
the impact of	military actions and the related displacement of the workforce	leads to	a 2.76 p. p.	decrease in the employment rate of the rural working-age population

Source: compiled by the authors based on the results of their own research

The regression equation obtained as a result of the econometric modelling demonstrated an inverse relationship between the level of rural employment and the number of agricultural enterprises. This relationship can be explained by the fact that during the analysed period, consolidation of enterprises in the sector occurred, which in turn led to restructuring and concentration of employment. A comparison of data from Tables 3 and 4 illustrates this: the number of large agricultural business entities tripled, while the number of employees in these entities increased by only 63.6%. A similar situation is observed in small and microbusinesses, where workforce reduction outpaces the decrease in the number of enterprises. Additionally, the introduction of innovative technologies, active automation and robotisation of production processes at enterprises, as well as the application of new forms of employment that are not always accounted for in statistics (e.g., remote work, which is not always formally contracted), also contribute to the decline in employment levels.

State-supported programs aimed at employment support and stimulation, which intended to form and ensure effective social and labour relations, failed to yield a significant positive effect. Particularly, such instruments as compensation to employers for wages paid to internally displaced persons (the compensation of UAH 8,000 (equivalent to the minimum wage) for a 3-month period resulted in only 16,480 persons employed during the entire program duration), provision of non-repayable grants to small and medium-sized businesses for creating new jobs, and engaging temporarily unemployed individuals in socially useful work under the government project Recovery Army (2022) have insufficient effect, according to the conducted research (State Employment Service, n.d.). The reasons for the catastrophic decline in rural employment are complex and require a comprehensive approach to resolution. Modelling rural employment and identifying the factors and their impact on employment provide a foundation for determining priority directions for implementing state policies and measures to increase rural employment.

Despite the modelling results showing an inverse relationship between rural employment levels and the number of agricultural enterprises, stimulating entrepreneurship development in rural areas remains a key priority of state policy aimed at ensuring rural employment amidst the risks posed by military aggression and exacerbation of demographic and economic crises. However, this must be accompanied by avoiding further enterprise consolidation and promoting the development of small and medium-sized businesses. As practice has shown, under conditions of Russian aggression, micro and small enterprises proved to be more resilient, quickly adapting to extreme operating conditions, and in the first months of the war, on a volunteer basis, they provided for the needs of volunteer formations, territorial defence, and the population in food supplies.

In terms of formalising employment, personal peasant farms (PPFs) hold significant potential. To this end, following the example of European Union countries, it is necessary to classify their economic activities as a separate category and extend special social insurance rules to the owners and members of family-type farms and their

hired workers; furthermore, it is essential to motivate and actively support the transformation of PPFs into family farming enterprises (FFE). Such measures are relevant from the standpoint of Ukraine's European integration ambitions and the need to harmonise Ukrainian legislation with that of the European Union. As of January 1, 2024, the total number of rural households in Ukraine amounted to 3,845.3 thousand, with an average household size of 2.10 persons per equivalent adult (State Statistics Service of Ukraine, n.d.). Expert assessments estimate the transformation potential of PPFs into FFEs at approximately 350 thousand (Malik *et al.*, 2024). To encourage PPF members to transition to FFEs, it is proposed to grant them priority rights to purchase land plots for FFE operation activities, while also providing access to affordable loans secured by guarantees from the Partial Credit Guarantee Fund for Agriculture. As I. Chornodid *et al.* (2021) note, solving the problem of informal labour relations should be based on the involvement of all necessary resources and means of regulation, including legal, economic and social ones.

Significant reserves for balancing the fundamental factors of the labour market and overcoming mono-structural employment in rural areas lie in the diversification of agricultural production. The livestock sector holds great potential for providing stable employment to rural residents. Agriculture contributes a substantial share of exports through crop production, including fodder grains. This indicates a considerable potential for the development of livestock industries driven by strengthening feed production. According to expert estimates, the production of milk or pork meat can create approximately 930 and 440 additional jobs, respectively, per 100,000 tons of exported grain (Khodakivska & Mohylnyi, 2020). Another priority direction for ensuring rural employment is the development of a diversified employment structure, namely the growth of processing industries, service cooperatives, and non-agricultural activities such as agritourism, rural and ecological (green) tourism, as well as the provision of various household and information-communication services.

An important priority of state policy to ensure rural employment and address the problem of rural depopulation is to encourage youth to return to or relocate to rural areas for residence and work by providing them with grant support and access to concessional loans to develop family entrepreneurship and start-ups in agriculture and other sectors. It is worth considering the option of transferring ownerless and unused municipal real estate along with the land plots (where they are located) to rural youth initiatives (either free of charge or for a symbolic fee) to establish micro- and small businesses in rural areas.

Significant potential for ensuring rural employment also lies in addressing the problem of low labour mobility among working-age rural residents, which is primarily related to attachment to housing and personal peasant farms. The rural labour market often exhibits regional imbalances, with some areas facing labour shortages despite job availability, while others experience high unemployment alongside an excess labour supply. This, in turn, requires measures to develop transport and engineering infrastructure (such as well-developed logistics, roads, scheduled and public transport) and the housing and utilities sector, including the possibility of free housing provision

or preferential terms for its purchase. Measures to increase rural employment should also include a complex of socio-psychological, organisational, legal, and economic activities aimed at creating favourable conditions for integrating internally displaced persons into rural communities, expanding their labour potential reproduction, and motivating war migrants to return from abroad.

The issues of rural employment are not exclusive to the Ukrainian economy. These challenges are common worldwide, including in highly developed countries. Identifying the causes of declining rural employment, isolating influencing factors, assessing their impact on employment levels, developing ways to prevent risks and mechanisms to eliminate disparities in rural labour markets, and defining state policy directions to ensure rural employment remain a constant focus of scientific research. For instance, the reduction of agriculture's share in rural employment structure, insufficient development of processing enterprises in rural areas, job shortages, seasonal employment, mismatch of labour supply qualifications with labour market demands, and weak transport infrastructure are characteristic not only of Ukraine but also of other countries, including the United Kingdom (Lindsay *et al.*, 2003). The authors importantly note that the severity of these problems intensifies with increasing remoteness of the rural labour market from centres of economic activity, which are mainly cities or industrial hubs.

Unemployment among rural youth is a pressing issue for many countries (Shuker & Sadik, 2024). The lack of available land for farming, poor infrastructure, financial isolation, and job shortages in rural areas contribute to the worsening situation in the labour market. However, state policies aimed at addressing these problems will remain ineffective and limited if they do not consider the full spectrum of issues, including gender equality, age, education, health-related discrimination in the labour market, and other factors (Usoro *et al.*, 2021). Analysing the relationship between population size, employment, and poverty in rural areas of Costa Rica, R. Rivera Alfaro & A. Porras Solis (2018) also concluded that a comprehensive approach is necessary to solve rural unemployment issues. In particular, the authors emphasise that employment strategies in rural areas should address wage levels, social security, institutional frameworks, labour mobility, and workforce relocation. They see a key role for local governments in stimulating rural labour markets, entrepreneurship, innovation, professional integration at the rural level, and inclusion.

Assessing the relationship between family farms and rural labour markets in Germany, D. Wuepper *et al.* (2021) concluded that this relationship is not causal; thus, supporting family farms as a means to combat rural unemployment in the country is ineffective. This finding partly confirms the results of the multifactorial correlation analysis conducted in this study, especially regarding the inverse relationship between the number of enterprises and rural employment levels in Ukraine. This is explained by the inefficiency of policies focused on enlarging agricultural enterprises, which led to restructuring and concentration of employment. Instead, promoting the development of small and micro-enterprises, including family farms, would be an important tool to ensure rural employment and formalisation.

G. Kukel *et al.* (2020) emphasise the need to select labour market regulation instruments that take into account the objective impact of global trends and aim to stimulate innovative employment and entrepreneurial activity among the rural population. In their view, supporting the development of organic agriculture constitutes such a tool. To address rural employment issues and develop competencies demanded in agriculture, E. Shahini & E. Shahini (2024) propose active implementation of cooperatives.

In studying employment opportunities for rural populations in India, R. Kapur (2019) identified key motivating factors for employment as wages, workplace location relative to home, availability of transport, working conditions, job duties, relationships with colleagues, training programs, work schedules, benefits and incentives, as well as provision of infrastructure, equipment, and tools. These demands correspond to the rural population of Ukraine, where the inability to find employment is often linked to low labour mobility, attachment to housing and land, and lack of transport infrastructure. Similar views are shared by S. Rosenberg *et al.* (2021). The main factors influencing rural employment levels in Romania, according to the authors, are low income levels and significant gaps in health-care reform, which have practically rendered quality medical services inaccessible to rural residents.

In examining rural-to-urban migration, H. Lyu *et al.* (2019) identified the primary cause as the lack of jobs and rising unemployment in rural areas rather than better living conditions or higher incomes in cities. In particular, the authors concluded that a 1% increase in the unemployment rate leads to the migration of an additional 16,000 individuals, based on their research and the proposed migration model. Therefore, political measures aimed at creating employment opportunities in rural areas are necessary to reduce migration rates.

All the above indicates the presence of similar rural employment challenges worldwide. Therefore, the positive experience of other countries in addressing such issues is valuable for Ukraine, particularly in promoting diversified rural employment, agricultural production diversification, combating long-term unemployment, encouraging young people to live and work in rural areas, and ensuring the integrated development of rural territories.

► Conclusions

The current characteristics of rural employment include changes in its structure, notably a declining share of agriculture as the primary type of economic activity, the restructuring and consolidation of work, a high level of informal employment, and lower wages compared to the urban population. As a result, this led to a significant decrease in the employment rate of the working-age rural population to 50.2% in 2023. Based on the results of economic-mathematical modelling of rural employment, the following conclusions were made: 1) the developed model shows that a 1% increase in real GDP ensures an increase in the employment rate of the working-age rural population by 7.33 percentage points; 2) a 1% increase in the number of unemployed persons undergoing vocational training ensures a rise in the employment rate by 2.2 percentage points; 3) a 1% increase in rural incomes ensures an increase in their employment rate by 4.14 percentage points; 4) a 1% increase

in investment volume reduces the employment rate by 1.8 percentage points; 5) a 1% increase in the number of enterprises leads to a decrease in the employment rate of the working-age rural population by 12.5 percentage points; 6) an increase in the labour market efficiency index by 0.1 leads to a decrease in the rural employment rate by approximately 0.45 percentage points; 7) the impact of military actions and the corresponding workforce displacement causes a decrease in the employment rate of the working-age rural population by 2.76 percentage points.

Priority paths for the implementation of state policy and measures to increase the employment level of the rural population have been identified in the following directions: stimulating entrepreneurship development in rural areas, supporting the market activity of micro and small entities; formalisation of rural employment by facilitating the transformation of household farms into family farms; diversification of agricultural production and development of a multi-sectoral employment structure; addressing

the problem of low labour mobility among rural residents; encouraging youth to relocate and work in rural areas; strengthening institutional capacity and resource sufficiency of rural territorial communities. Promising directions for further research in this context include the development of an organisational and economic mechanism to ensure rural employment, as well as the substantiation of methods and instruments for its implementation aimed at addressing the current situation in the rural labour market and resolving employment challenges in rural areas.

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Зайнятість сільського населення України: якісний і кількісний виміри

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► **Анотація.** Сільський ринок праці в сучасних умовах зазнав суттєвих трансформацій, зумовлених зміною ролі та формату впливу аграрного сектору на розвиток сільських територій країни, адміністративно-територіальною реформою та процесами децентралізації, повномасштабною агресією РФ. Мета роботи – оцінити вплив окремих чинників на зайнятість сільського населення в Україні та визначити основні шляхи підвищення її рівня. Методологічною основою дослідження був системний підхід. В аналітичних дослідженнях застосовано порівняльний аналіз, метод середніх і відносних величин, графічний метод, трендовий, індексний, кореляційно-регресійний (багатофакторна модель) аналізу тощо. Проаналізовано тенденції зайнятості сільського населення в Україні за 2000-2023 рр. З'ясовано, що з 2013 р. рівень зайнятості сільського населення працездатного віку має спадну динаміку. Визначено основні проблеми та характерні особливості зайнятості сільського населення в сучасних умовах. Проведено економіко-математичне моделювання рівня зайнятості сільського населення працездатного віку, результати якого засвідчили пряму його залежність від реального валового внутрішнього продукту, кількості безробітних, які проходили професійне навчання, рівня заробітної плати. Негативний вплив на рівень зайнятості сільського населення мають збільшення обсягів інвестування та кількості підприємств, що пояснюється підвищенням технологічності виробництва; запровадженням нових форм зайнятості, укрупненням та реструктуризацією зайнятості, та воєнні дії. Окреслено пріоритетні напрями підвищення рівня зайнятості сільського населення. Основні положення, кількісні оцінки, пропозиції і висновки, викладені у статті, можуть бути використані державними органами управління при перегляді прийнятих документів та під час розроблення нових стратегічних програм з питань зайнятості сільського населення з урахуванням викликів сьогодення, внутрішніх загроз і тривалої російсько-української війни

► **Ключові слова:** сільський ринок праці; чинники впливу; економіко-математичне моделювання; проблеми; пріоритети



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Development of grain logistics in Ukraine

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► **Abstract.** In the modern environment, new dangers are emerging that affect the current situation of grain logistics in Ukraine and must be countered to offset their adverse impact. The purpose of this study was to investigate the current trends in the grain logistics market and identify emerging challenges and threats, as well as to formulate an algorithm of actions for the development of the agricultural sector infrastructure during and after the war. When considering the problems and objectives of the study, the authors of the study employed scientific methods, namely: dialectical, systematic approach, comparative analysis, tabular and graphical, monographic, and deductive, which determined the method and sequence of solving the tasks. The study analysed the monthly dynamics of grain cargo transportation by rail for 2021-2024. The tariffs for internal and international transportation of grain crops by road, as well as the cost of procurement services of the branches of the Joint Stock Company "State Food and Grain Corporation of Ukraine" were investigated. The study found that during the period of martial law, the grain business adapted to the conditions that arose and was gradually restoring damaged property, expanding existing capacities, and building new ones. The study showed that in 2023-2024, 1.9 million tonnes of elevator capacities were built in the regions of Ukraine, including transshipment terminals, and the total elevator capacity at the beginning of 2024 was approximately 41.4 million tonnes. The key factors that contributed to the normalisation of trade logistics in 2022 were substantiated. The study analysed the exports and imports of grain crops by various modes of transport and examined the main buying countries and the largest exporters of Ukrainian grain. The study provides a scientific substantiation for the EU-Ukraine Solidarity Road Initiative. A reasoning was provided for the algorithm of actions for further development of the agricultural sector infrastructure during and after the end of the war to rebuild it. The use of the proposals set out in this study will enable a better assessment of the state of Ukraine's grain logistics during

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the war and post-war reconstruction. The proposals and practical recommendations of the study may be useful for government officials, farmers, and other agricultural producers, as they can be used to develop relevant programmes and measures to support the development of grain logistics in Ukraine

► **Keywords:** transportation; storage of products; railway; elevator capacities; ports of Greater Odesa; action algorithm

► Introduction

Ukraine is one of the world's largest grain producers and exporters. Prior to the outbreak of hostilities, over 70% of Ukraine's grain production was exported, with over 90% of exports taking place by sea via Black Sea ports (Yanovska *et al.*, 2025). Grain production and exports are one of the pillars of the country's modern economy. In the 2022/2023 marketing year, Ukraine ranked 6th (15 million tonnes) among the world's largest exporting countries, behind Russia (44.5 million tonnes), Australia (32.5 million tonnes), Canada (26 million tonnes), the United States (21.1 million tonnes), and France (18 million tonnes) (TOP-10 wheat producing countries..., 2023). In 2024, the volume of agricultural exports reached the pre-war level and amounted to USD 24.5 bn (78.3 million tonnes) or 59% of total exports. Significant exports (48.2% of total agricultural exports) were accounted for by cereals: maize – 29.6 million tonnes (USD 5 bn); winter wheat – 20.6 million tonnes (USD 3.7 bn); rapeseed – 3.8 million tonnes (USD 1.8 bn); soybeans – 3.4 million tonnes (USD 1.3 bn) (Historical record..., 2025). One of the determining factors in achieving such prominent results during the hostilities was the restored grain logistics, which necessitated its more thorough study and the development of areas for its effective functioning in the context of instability and post-war reconstruction.

Y.J. Kim & B.K. Lee (2022) focused on preventing grain spoilage and preserving its qualities through the widespread use of containers and grain logistics systems. The researchers found that the cost of containerised grain transportation was lower than that of conventional bulk grain. Y. Rudyk *et al.* (2023) developed methods for evaluating logistics facilities based on their geographical location and active user involvement. They will facilitate the development of new, safe routes as an element in the food supply chain, including grain.

H. Kryshstal (2023) investigated the development of agrarian logistics during military operations, reflecting both theoretical aspects (definition of logistics and agrarian logistics) and analysing the overall state of agrarian logistics and grain logistics specifically. The researcher proved that without improvement of logistics it would be impossible to unlock the full potential of the country's agricultural sector. The regression models developed by V. Kolodiichuk & Yu. Dubnevych (2020) are advisable to be used to predict the performance indicators of grain logistics systems. The conceptual model developed by A. Muradian *et al.* (2023), The Smart Port, through the symbiosis of the theoretical foundations of technological development and the UN Sustainable Development Goals, will contribute to the expansion of the modern scientific foundations of transport logistics systems. The researchers identified the prospects for growth to the fourth category of development of Ukrainian ports, and a model for optimising the management of logistics flows for their successful development by 2038 was proposed.

H. Kryshstal (2023) identified the key development vectors of Ukrainian agriculture during the military operations, namely: increasing the area under export-oriented crops, promoting job growth in rural areas, breeding new varieties, modernising processing enterprises and grain logistics infrastructure. D.-Y. Li *et al.* (2023) investigated the third-generation Beidou navigation positioning system and the benefits of its use in logistics tracking and emergency management in the grain industry. L.-G. Ji *et al.* (2023) identified priority areas for the development of grain logistics, including progressive approaches to planning grain logistics facilities, improvement of logistics hubs, technical re-equipment, optimisation of multimodal traffic flows, and management and control systems. The researchers paid particular attention to the use of intelligent innovative technologies and training of highly qualified personnel in logistics.

N. Potori & Z. Molnár (2024) highlighted the problem of disruption of export-import logistics links in the transportation of maize caused by military operations in Ukraine, providing a detailed analysis of changes in the structure of bilateral trade and describing the effects of these disruptions. Therewith, the researchers substantiated the temporary nature of this phenomenon, the absence of threats to the EU grain market, and the significance of adaptive and secure logistics in the face of geopolitical instability. E.S. Farias & M.A.S. Martins (2023) investigated the choice of the best location for the establishment of distribution centres, factoring in the delivery of crop products to consumers at minimal cost. Their developed mathematical model for optimising wheat logistics costs can be adapted to other sectors of agricultural production. A.B. Hemmelgarn *et al.* (2023) considered an alternative technology for harvesting main production and by-products of grain, based on a single-pass system where main products and by-products are harvested as bulk material, stored and preserved by anaerobic fermentation, and subsequently transported together to a processing plant.

The purpose of the present study was to assess the current state and trends, identify challenges and threats in the field of grain logistics, as well as substantiate and shape the development vectors of grain logistics infrastructure in the context of instability and the post-war period. The objectives of the study were as follows: to study and systematise scientific evidence in improving and developing the grain logistics sector; to analyse the current state and features of grain logistics in Ukraine; to analyse grain exports by various modes of transport.

► Materials and methods

The basis of theoretical research on grain logistics in Ukraine included the scientific studies of researchers who addressed this issue. The study used data from the

State Statistics Service of Ukraine (n.d.) (on gross harvest of cereals and legumes in weight after processing), data from the State Customs Service of Ukraine (Exports of Ukrainian..., 2024) and the Ministry of Agrarian Policy and Food of Ukraine (2025), data from the State Food and Grain Company of Ukraine (Cost of procurement..., n.d.), data from the global network regarding information on monthly volumes of grain transportation in 2021-2024 of the Ukrainian Railways (Grain transportation..., 2024), as well as data from logistics companies (on the cost of internal and international grain transportation in 2024 (Ukratologistic Group, n.d.), information from the country's main elevator website Elevatorist.com (Grain storage capacities..., 2024).

The study of grain logistics in Ukraine was conducted based on the dialectical method. The application of this method helped to assess the processes and phenomena of the national grain logistics market that directly affect it. The systematic approach helped to formulate the essence of the stated problem and choose ways to solve it. The analysis method was employed to substantiate the key factors that contributed to the normalisation of trade logistics during the war. The monographic method was applied to determine the price gaps in the cost of storing grain crops at elevators in Ukraine. The tabular and graphical methods were used to illustrate the results of the study in the form of tables and figures. To determine the cause-and-effect relationships in the Ukrainian grain logistics market, which involves identifying current trends in the development of this market, as well as challenges and dangers, a comparative analysis of indicators of grain cargo transportation by rail, the cost of internal and international road transportation of grain, the availability of elevator capacities and exports of major types of grain crops in the pre-war and war periods was used. The deductive method was employed to substantiate the risks that may hinder the development of infrastructure and the restoration of logistics chains in the future.

The key stages of the study included the analysis and systematisation of research by scientists from around the world on the development of the grain logistics market. A study of the current state of the grain logistics market in Ukraine, including substantiation of the indicators of grain rail transport when traffic through the "Ukrainian sea corridor" was accelerating (2023-2024), identification of significant problems with the growth of grain transportation tariffs and the cost of storing grain at elevators, as well as an assessment of available port capacities. The study analysed grain exports abroad by sea, rail, and road. The volume of losses of grain storage capacities was determined, as well as their recovery from the beginning of 2022 to 2024. The initiative between Ukraine and the European Union, which simplified the import and export of agricultural products, was substantiated. An algorithm of actions for the further development of the agricultural sector infrastructure after the end of the war and its reconstruction was proposed.

► Results and discussion

Ukraine has a well-developed transport and logistics infrastructure and a strong agricultural sector, which is why M. Kovalova (2024) noted that these features of Ukraine

contributed to the competitiveness of national companies in the international market. Before the war, Ukrainian agribusiness was focused on large warehouses and expensive modern automation systems, as scaling provided higher efficiency. N. Vasylytsiv (2023) addressed the fact that these solutions did not work at all when enemy missiles hit the warehouses of companies. Therefore, reliability became much more significant than efficiency. According to the researcher, in the current military conditions, Ukrainian logistics business participants adapted and transformed their logistics processes, including optimising logistics routes, cooperation with international partners, considering risks and focusing on processes that require them.

O. Penkova & A. Kharenko (2023) identified the positive influence of marketing and sales logistics during military operations on the prospects for growth in grain sales in European markets during the post-war recovery. The implementation of the proposed measures will enable Ukrainian exporters to find their niche in these markets and restore the export potential of grains and oilseeds to the markets of Africa and Asia. The hostilities also contributed to the emergence of such a negative phenomenon as illegal grain supply chains. J.El Baz *et al.* (2025) were the first to investigate the mechanism of fraudulent supply chains and supply chains of looted grain. O. Zerkina *et al.* (2022) proposed a structural model of institutional support for the reproductive logistics of the grain market, which is focused on the integration of its 'shadow' elements into the sphere of regulated supply chains and the fair redistribution of added value between their links.

Cargo is transported in Ukraine through the internal transport network, which includes roads, railways, inland river routes, and coastal sea routes without calling at foreign ports. The longest road network is the motorway network, with a length of 169.5 thsd km. Rail transport accounts for the bulk of grain shipments, with road transport also playing an essential role, as well as other modes such as water and river transport. An analysis of the structure of internal grain transportation shows that rail transport accounts for over 60% of all shipments, road transport accounts for 35%, and other modes of transport account for 5%. The length of railway tracks in operation is about 22 thsd km, including about 10 thsd km of electrified tracks. The monthly dynamics of grain cargo of JSC Ukrainian Railways reflects the modification of the logistics capabilities of grain exports after Russia's full-scale invasion and correlates with the capabilities of existing export routes, particularly through the ports of Greater Odesa (Fig. 1). In January-April 2024, the high volumes of grain transportation by rail correlated with the maximum exports abroad in February-May via the Ukrainian sea corridor, when grain shipments each month were within 3.5-4.0 million tonnes. The significant performance of grain rail transport in early 2024 was a continuation of the trend that began in November 2023, when the movement of grain cargo through the Ukrainian sea corridor was accelerating. It was found that in 2024, over 100,000 road carriers were engaged in internal transportation services. In 2024, the tariffs for road transport of grain crops increased by 1.3 times compared to 2022 and amounted to UAH 4.2 per t/km. As for international road transportation in Europe, the cost of grain carriage by grain carriers ranged

from EUR 80 to 200 per tonne, and grain transportation by tents – from EUR 1.5 to 4.0 per tonne. The cost of procurement services provided by the state-owned company – branches of the State Food and Grain Company of Ukraine is presented in Table 1. For agricultural enterprises from

different regions of Ukraine, services for receiving, drying, cleaning, and shipping grain crops in 2024/2025 increased by 1.3 times compared to 2022/2023 marketing years. This was caused by greater prices for petrol and diesel fuel, as well as increased wages, depreciation, and other factors.

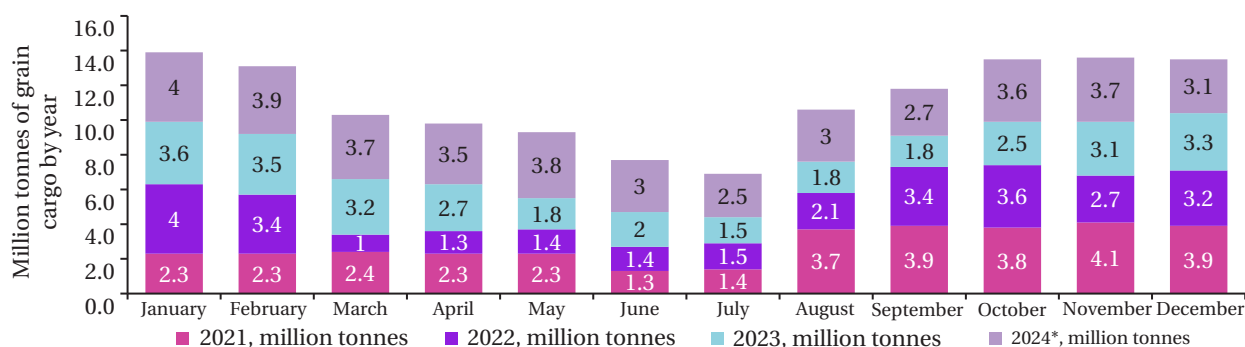


Figure 1. Monthly dynamics of grain transportation by JSC Ukrainian Railways, 2021-2024

Notes: the data in the chart for November-December 2024 are estimated

Source: built based on data from Grain transportation by rail in January-September 2024 reached an absolute record for the years of Ukraine's independence (2024)

Table 1. The cost of procurement services of the branches of the Joint Stock Company "State Food and Grain Company of Ukraine" for the 2024/2025 marketing year, UAH (including VAT)

Company of Ukraine for the 2021/2022 marketing year, CHT (including HT)							
Region	Delivery		Drying, UAH/t-%	Cleaning, UAH/t-%	Storage, UAH/t/day	Consignment	
	Automotive, UAH/t	Railway, UAH/t				Automotive, UAH/t	Railway, UAH/t
Cereal crops							
Northern	24-29	29	88-110	34-40	99-115	150-200	150-200
Southern	13-32	-	120-164	30	97-112	181-198	203
Eastern	28	-	146-180	21-31	74-117	190-210	190-210
Central	17-36	17-64	105-150	22-42	101-115	165-221	167-221
Western	26	53	120	28	119	189	219

Source: calculated based on data from Cost of procurement services for the 2024/2025 marketing year (n.d.)

Due to the risks posed by the war, most agricultural producers from the frontline areas are transporting grain for storage to elevators in central Ukraine to avoid losing their crops and to wait for prices to rise and sell their products at more favourable prices later. The appreciation of the USD to 41 UAH per 1 USD led to an increase in the cost of grain storage to an average of 107 UAH/t/day. During the period of martial law, the grain business adapted to the conditions and is gradually restoring damaged property, expanding existing facilities and building new ones. This was happening even in the regions bordering the enemy. Over 2023-2024, 1.9 million tonnes of elevator

capacity was built in the regions of Ukraine, including transshipment terminals. By region, the largest increase in capacity over the relevant period was in Khmelnytskyi – 300 thousand tonnes, Chernihiv and Poltava – 240 thousand tonnes each, Vinnytsia – 230 thousand tonnes, Volyn – 192 thousand tonnes, and Ternopil – 170 thousand tonnes. As of March 2024, the total elevator capacity of Ukraine's regions was approximately 41.4 million tonnes. However, despite a certain degree of restoration of elevator capacities, only Poltava, Zakarpattia, Odesa, and Mykolaiv regions were fully provided with grain storage facilities with the relevant storage capacity (Table 2).

Table 2. Elevator capacities by region of Ukraine

Region	Number of granaries (as of March 2024)	Total grain storage capacity (as of March 2024), thousand tonnes	Grain storage capacity increased, decreased (+/-) compared to 2022 to March 2024, thousand tonnes	Gross harvest of grains and pulses in weight after processing in 2023, thousand tonnes
Western regions of Ukraine				
Chernivtsi	11	≈264	+30	755
Ivano-Frankivsk	15	580	+35	881
Zakarpattia	7	≈700	+20	308
Lviv	42	1,200	+85	1,771
Ternopil	56	2,000	+170	2,856

Table 2, Continued

Region	Number of granaries (as of March 2024)	Total grain storage capacity (as of March 2024), thousand tonnes	Grain storage capacity increased, decreased (+/-) compared to 2022 to March 2024, thousand tonnes	Gross harvest of grains and pulses in weight after processing in 2023, thousand tonnes
Volyn	33	1,100	+192	1,372
Rivne	25	1,100	+73	1,270
Northern regions of Ukraine				
Zhytomyr	52	1,400	+50	2,418
Kyiv	≈70	2,800	+40	3,783
Chernihiv	≈75	3,300	+240	4,900
Sumy	≈49	2,600	-31	3,574
Central regions of Ukraine				
Cherkasy	67	2,800	+90	4,475
Khmelnyskyi	75	3,400	+300	3,700
Vinnitsia	104	4,400	+230	4,992
Kirovohrad	92	3,600	+50	3,992
Poltava	107	5,500	+240	5,277
Eastern regions of Ukraine				
Kharkiv	≈64	2,200	-490	2,466
Donetsk	–	–	–	–
Luhansk	–	–	–	–
Southern regions of Ukraine				
Dnipropetrovsk	90	3,000	-101	3,397
Mykolaiv	≈60	3,500	+10	2,413
Odesa	≈90	5,100	+50	4,048
Kherson	–	–	–	–
Zaporizhzhia	–	–	–	383
Total	≈1,184	≈41,400	1905	59,031

Notes: information on the occupied areas is not available due to the war

Source: calculated based on data from the State Statistics Service of Ukraine (n.d.) and from the website Elevatorist.com (Grain storage capacities..., 2024)

T. Luchnikova *et al.* (2023) investigated the problems of losses incurred by grain exports caused by the blocking of Ukrainian seaports under martial law, as well as the restoration of the flow of grain crops with the help of international partners and the professionalism of the grain logistics market. The researchers noted that despite the closure of the grain corridor and the clash of interests with Poland, which was quickly resolved, in the future Ukraine will manage to strengthen new logistics routes for grain exports. Therefore, the claim of O. Bodnar *et al.* (2024) that the hostilities caused a collapse in food exports appears to be debatable and exaggerated.

Russia's full-scale war against Ukraine led to the blockade of the Black and Azov Seas ports by the aggressor country, and therefore traders were forced to sell grain abroad via land and river routes to European countries with subsequent transshipment in European ports of the Black and Baltic Seas. The capacity of land and river crossings is severely limited. Specifically, Ukraine used to be capable of exporting 6-7 million tonnes per month via seaports, but in May 2022, exports via all road, rail, and river routes amounted to only 1.5 million tonnes. Between 1 July 2022 and 30 June 2023, Ukraine exported about 49.0 million tonnes of grain pulses, including 16.8 million

tonnes of wheat, 2.7 million tonnes of barley, and 29.1 million tonnes of maize (Ukraine exported almost..., 2023). O. Iatsenko (2024) substantiated the factors that contributed to the establishment of trade logistics in 2022:

1. To facilitate trade in agricultural products in times of war, on 22 July 2022, Ukraine signed the Black Sea Grain Initiative with the United Nations and the Republic of Turkey. Within the framework of this initiative, from August 2022 to March 2023, over 25 million tonnes of Ukrainian grain were exported.

2. To support the export logistics of grain in the absence of stable alternative routes and the sea blockade, Ukraine and the European Union signed the Agreement on Liberalisation of Road Freight Transport, which supports Ukraine in the field of transport, or 'transport visa-free regime'.

3. Construction of new checkpoints for road and rail transport and expansion of the capacity of existing checkpoints.

4. Increase of the capacity of the port infrastructure on the Danube.

In 2024, Ukraine had enough port capacities to cover all its export needs. Grain crops were exported from the ports of Greater Odesa – Chornomorsk, Pivdennyi, Odesa, as well as from ports on the Danube (Table 3).

Table 3. Total volumes of grain cargo transported by main types of traffic, million tonnes

Connection type	Year			
	2021	2022	2023	2024*
Transported in total, including	33.7	28.9	30.6	40.5
export, including	29.3	22.6	22.7	34.7
ports, including	28.7	15.1	14.3	29.5
Odesa	21.2	12.7	13.1	28.2
Danube	0.002	0.8	1.2	1.3
other ports	7.4	1.5	0	0.0
Border crossings	0.59	7.4	8.4	5.2
import	0.2	0.1	0.03	0.01
transit	0.6	0.5	0.4	0.5

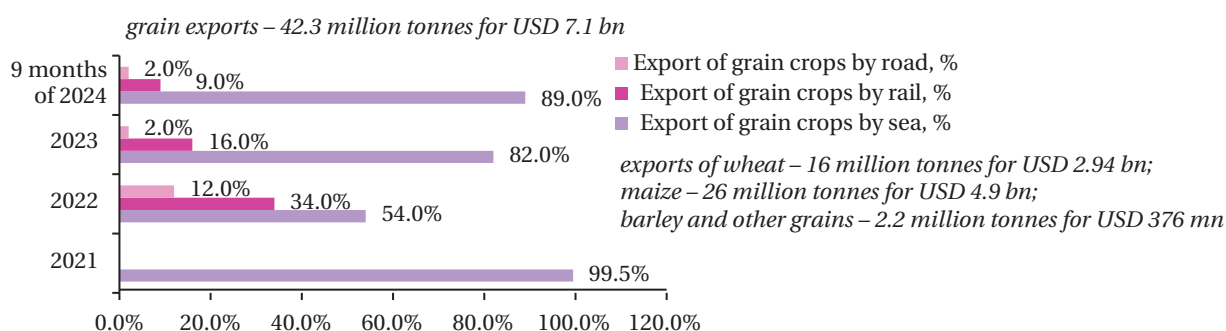
Notes: *Annual data for 2024 – estimated

Source: calculated based on data from Valery Tkachov: Logistical possibilities of grain export by rail in 2023-2024 (2024)

In the first 10 months of 2024, 38.9% more (33.7 million tonnes) was transported by rail compared to the corresponding 10-month period of 2023 (24.3 million tonnes). During the same analysed period, exports totalled 28.9 million tonnes, an increase of 64.3% compared to the first ten months of 2023. It was found that these figures were the greatest for the entire period under study. In 2024, the total volume of grain transportation by rail could reach 40.5 million tonnes. The opening of the 'sea corridor' in August 2023 had a massive positive impact on the opportunities for exporters of grain and other cargoes. The operation of the corridor has largely enabled the year-end increase in cargo transshipment in Ukrainian ports by 5% year-on-year (to 62 million tonnes) (A record 8 million..., 2024). The study substantiated the key factors influencing the volumes of transportation, namely: the shift in the timing of the 2023

harvest exports to the first half of 2024; the war caused a shortage of drivers, the primary reason being mobilisation measures within the country, which prompted farmers to reorient their cargoes from road to rail; and the absence of logistical restrictions on grain exports through the ports of Greater Odesa and western border crossings.

Grain cargo is transported to Ukrainian sea elevators by road and rail and then transhipped to special vessels. Containers with a capacity of 18-25 tonnes are suitable for small batches of grain, which are loaded at the place of production or purchase, sealed and delivered to ports. In total, in 9 months of 2024, Ukraine exported USD 7.1 bn worth of grain cargo, or more than 42 million tonnes (Exports of Ukrainian..., 2024). The resumption of maritime traffic resulted in 89% of agricultural products being exported by sea, 9% by rail, and only 2% by road (Fig. 2).

**Figure 2.** Grain exports by various modes of transport, 2021-2023 and 9 months of 2024

Source: calculated by the authors of this study based on data from Agricultural exports-2023: How much and where were grains and oils sold (2024) and Exports of Ukrainian agricultural products have increased significantly compared to last year (2024)

For comparison, in 2023, 82% of grain crops were exported by sea, 16% – by rail, and 2% – by road. The main buyers of wheat were Spain, the Republic of Turkey, and Romania. Accordingly, they accounted for 23%, 15%, and 14% of total exports of this crop. The main buyers of maize were the People's Republic of China, with an export share of about 22%, Spain – 13.7%, and Romania – 11.5%. Ukrainian barley was bought by the Republic of Turkey, the People's Republic of China, and Spain, and sorghum by Romania, Italy, and Poland (Agricultural exports-2023..., 2024).

Ukraine exported 33.0 million tonnes of grains and pulses since the beginning of 2024/25 marketing year as

of 4 April 2025. In terms of crops, since the beginning of the current season, Ukraine has exported 13.3 million tonnes of wheat, 2.2 million tonnes of barley, 17.1 million tonnes of maize, and 10.8 thousand tonnes of rye (Ministry of Agrarian Policy and Food of Ukraine, 2025). It is also worth noting the largest companies selling grain grown in Ukraine abroad: Kernel, French grain trader Louis Dreyfus, US agricultural companies Cargill and Archer Daniels Midland, the largest Ukrainian agricultural producers of grain crops Nibulon and Agroprosperis, as well as Swiss and Chinese companies Viterra and Cofco International.

The situation with imports is somewhat different. Specifically, 80% of agricultural products are imported to Ukraine by road, 18% – by sea, and only 2% – by rail. The key reason for this is that imports come from European countries, unlike exports, where goods are delivered all over the world. Ukraine's agricultural sector ensures a stable supply of products to foreign markets and meets internal needs through imports. The EU-Ukraine Solidarity Initiative, which is a lifeline for the Ukrainian economy, played a prominent role in this process. The primary goal of the initiative is to improve transport links between Ukraine and the European Union, including the development of alternative logistics routes by rail, road, and inland waterways. In this case, it is advisable to calculate a fuzzy model and create conditions for the use of alternative logistics chains in the process of grain delivery (Medvediev *et al.*, 2024). Within the framework of the initiative, the European Union allocated EUR 7 bn for leading infrastructure projects, allowing Ukrainian and Moldovan unions to take part; in 2023, the EU financed the improvement of infrastructure connections with Ukraine in the energy, digital, and transport sectors. In May 2023, EUR 250 million was invested to improve transport links between Ukraine, Moldova, and the European Union.

In times of war, it is adequate to use the experience of intermodal transport. C.H.F. de Faria *et al.* (2024)

employed a simulation-optimisation approach to planning an intermodal grain export chain through the collaboration of road freight transport, as well as rail and sea modes. M.G.M. Peixoto *et al.* (2022) also studied the efficiency of intermodal logistics, specifically intermodal terminals, and found that the best operational performance of their work can be ensured by using their structure and available resource potential. In 2022-2023, EUR 226 million was allocated to improve the logistics of motorways between Ukraine and the Republic of Moldova. Over the years, logistics routes with the Republic of Poland, Romania, and Germany were markedly improved, with an additional EUR 240 mn allocated for development. New agreements on road transport between the European Union, Ukraine, and Moldova will significantly increase the number of road transports to Western European countries. The rail links between the EU and Ukraine are the first step in connecting the European gauge tracks from Krakow (Poland) to Lviv (Ukraine) and from Iași (Romania) to Chisinau (Moldova). This lays the groundwork for improved logistics for rail freight in the coming years and increased freight traffic to the west and south. In 2022-2024, grain logistics losses will amount to more than USD 25 bn, 89% of which will come from losses due to the reorientation of logistics flows caused by the blocking of Black Sea ports (Table 4).

Table 4. Estimation of losses, potential risks, and algorithm of actions of grain logistics entities to restore infrastructure

No.	Element	Period	USD bn
Losses			
1	Blocking of Black Sea ports and reorienting of logistics flows	2022-2024	22.5
2	Lower grain prices caused by deteriorating market conditions	2022-2024	1.5
3	Destruction, damage, and loss of grain storage facilities due to occupation	2022-2024	1.3
Potential risks			
1	Loss of logistics facilities and disruption of logistics chains due to the spread of hostilities to new territories	period of hostilities	–
2	Insufficient state funding for logistics infrastructure restoration projects and difficult access to bank loans	during and after hostilities	–
3	Deterioration of the investment climate, imperfect legal protection of investment activities, challenges in doing business, high tax burden	during and after hostilities	–
Areas and projects of restoration			
1	Relocation of some logistics facilities to the western regions of Ukraine (transshipment hubs and cross-border terminals)	period of hostilities	2.3
2	Funding for the development of river logistics infrastructure and the creation of new routes for export and internal movement of agricultural products	during and after hostilities	
3	Creation of a railway transport corridor to the nearest Baltic ports through the construction of wide gauge sections	during and after hostilities	
4	Compensation for damages to grain terminals in the Black Sea ports due to blocking and damage	after hostilities	4

Source: developed by the authors of this study based on data from O. Zakharchuk *et al.* (2023)

The identified volumes of losses and potential risks during the period of instability helped shape the areas and costs of projects to restore logistics infrastructure and optimise cargo flows. Specifically, the relocation of some logistics infrastructure facilities, the development of river logistics, and the construction of a railway corridor to European ports are promising areas. The estimated cost of these projects is USD 2.3 billion. To compensate for the damage to the port grain infrastructure, the required funding should amount to about USD 4 billion.

► Conclusions

In 2024, there were no logistical restrictions for grain exports by rail, and grain was transported to the ports of Greater Odesa, to the western border crossings, and to the Danube ports. This year saw an increase in internal road transport of grain cargoes to UAH 4.2 per t/km, the price of international road transport in Europe ranged from EUR 80 to 200 per tonne, and the price of grain transport by tents from EUR 1.5 to 4.0 per tonne. It was found that due to the war, most agricultural producers from the frontline areas

exported grain for storage to elevators in central Ukraine not to lose their harvest, as well as to wait for higher prices and later sell their products at a more favourable price. The rise in the USD in 2024 to UAH 41 per 1 USD led to an average increase in the cost of grain storage to 107 UAH/t/day.

In 2023-2024, Ukraine built 1.9 million tonnes of elevator capacity, including transshipment terminals. As of the beginning of 2024, the total elevator capacities of the regions of Ukraine amounted to approximately 41.4 million tonnes, and their partial restoration by March of this year contributed to the provision of grain storage facilities with the corresponding storage capacity in full in only 4 regions of Ukraine – Poltava, Zakarpattia, Odesa, and Mykolaiv. The study identified the factors influencing the volume of grain cargo transportation by rail, namely: the shift in the timing of grain exports from 2023 to the first six months of next year; mobilisation measures related to the war prompted agricultural producers to change the transportation of grain cargo from road to rail; and the absence of logistical restrictions on grain exports abroad. It was substantiated that the resumption of maritime traffic was the primary reason 89% of total grain exports were carried

out by sea in 2024. In turn, exporters transported 9% of grain cargo by rail, and only 2% by road. As for imports, the situation was quite the opposite: 80% of imported agricultural products were transported by road, 18% – by sea, and 2% – by rail. This was mainly conditioned by imports from European countries, as opposed to exports, where goods are shipped all over the world. In the future, an algorithm of actions for further development of the agricultural sector infrastructure during and after the end of the war and its reconstruction is proposed, which would consider the key risks of further escalation, losses calculated as of the end of 2024, the primary tasks and the necessary funds for their implementation.

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► Conflict of interest

None.

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Розвиток зернової логістики в Україні

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► **Анотація.** В сучасних умовах з'являються нові небезпеки, які впливають на поточне становище зернової логістики в Україні та яким необхідно протидіяти, щоб нівелювати їхній несприятливий вплив. Метою статті було дослідження сучасних тенденцій на ринку логістики зернових та виявлення нових викликів і загроз, а також формування алгоритму дій для розвитку інфраструктури агросектору під час та після закінчення війни. При розгляді проблем та завдань дослідження авторами статті застосовувались наукові методи, а саме: діалектичний, системний підхід, порівняльний аналіз, табличний та графічний, монографічний, а також дедуктивний, які визначають спосіб і послідовність рішення поставлених завдань. У роботі проаналізовано щомісячну динаміку транспортування зернових вантажів залізницею за 2021-2024 рр. Досліджено тарифи на внутрішні та міжнародні перевезення урожаю зернових культур автомобільним транспортом, а також вартість послуг заготівельної діяльності філій Акціонерного товариства «Державно продовольчо-зернової корпорації України». Встановлено, що у період військового стану зерновий бізнес адаптувався до умов, які виникли та поступово відновлює пошкоджене майно, розширює наявні потужності, а також будує нові. Простежено, що за 2023-2024 рр. в областях України побудували 1,9 млн тонн елеваторних потужностей разом з місткостями перевантажувальних терміналів, а загальні елеваторні потужності на початок 2024 року складають приблизно 41,4 млн тонн. Обґрунтовано основні фактори, які сприяли нормалізації торговельної логістики у 2022 р. Проаналізовано експорт та імпорт зернових культур різними видами транспорту, а також розглянуто основні країни-покупці та найбільші компанії експортери українських зернових. В дослідженні науково обґрунтовано ініціативу «Шляхи солідарності Україна – ЄС». Зроблене аргументоване обґрунтування алгоритму дій для подальшого розвитку інфраструктури агросектору під час та після закінчення війни щодо його відбудови. Використання викладених у цьому дослідженні пропозицій дозволить краще оцінювати стан зернової логістики України в умовах війни та повоєнної відбудови. Пропозиції та практичні рекомендації дослідження можуть бути корисними працівникам органів державного управління, фермерам, а також іншими агровиробниками, тому що можуть бути застосовані при розробці належних програм та заходів, направлених на підтримку розвитку зернової логістики в Україні

► **Ключові слова:** транспортні перевезення; зберігання продукції; залізниця; елеваторні потужності; порти Великої Одеси; алгоритм дій



UDC 355.6

Ensuring food security in communities amid wartime challenges

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► **Abstract.** This study aimed to analyse the food security of local communities in Ukraine under wartime challenges, with a focus on the impact of active hostilities on food resources, production levels, stocks, and humanitarian support. Additionally, the analysis considered the influence of tourism, especially in transit and remote communities. The study utilised data from statistical reports of the State Statistics Service of Ukraine, information from local self-government bodies, international organisations such as the World Food Programme and the International Committee of the Red Cross, as well as survey results from residents of three communities: Kharkiv, Dnipropetrovsk, and Lviv regions. The survey covered issues regarding food availability, basic needs for essential food products, and the evaluation of humanitarian aid. The research employed online survey forms and telephone interviews, along with public information requests to local self-government bodies. The analysis revealed that the frontline community (Kharkiv region) faces the most significant challenges: 65% of respondents reported a severe shortage of basic foodstuffs, compared to 40% in the transit community (Dnipropetrovsk region) and 20% in the remote community (Lviv region). Official sources confirmed that after the outbreak of full-scale hostilities in 2022, the production volumes of key crops in Ukraine decreased by 40% in the frontline community, while food stocks reached critically low levels. International aid plays a crucial role in stabilising the situation, particularly by ensuring basic food needs and strengthening community resilience. The study results underscore the necessity of enhancing cooperation between territorial communities, government institutions, and humanitarian organisations, as well as improving food resource management strategies. Furthermore, the collected data emphasise the importance of considering regional specifics for effective humanitarian planning and the economic recovery of communities

► **Keywords:** humanitarian aid; territorial communities; survey of residents; martial law

► Introduction

Ensuring food security is one of the key tasks in modern conditions, especially in the context of challenges posed by active hostilities. War radically alters the functioning of the agro-industrial complex, creating significant obstacles to food production, storage, and distribution. The complexity lies not only in the physical destruction of infrastructure but also in disruptions to logistics chains, economic challenges for local producers, and the exacerbation of social needs within communities (Ortega-Beltran & Bandyopadhyay, 2023).

The scientific community has devoted considerable attention to the issue of food security in crisis conditions. Studies conducted between 2021 and 2024 focus on the impact of global and local crises on agriculture, food

systems, and strategies for stabilisation. For instance, analyses of food resilience highlight the importance of adapting resource management systems to wartime conditions; however, these analyses do not sufficiently consider regional-level specifics, particularly the interaction between local authorities, citizens, and international organisations (Food security and..., 2023).

Studying the current state of food security in communities affected by war will help identify key challenges and develop approaches to address them (VI Kharkiv International..., 2022). This research aims to analyse the impact of wartime conditions on food supply in different types of communities and assess the capacity for recovery and adaptation to new realities. The International Committee

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of the Red Cross (ICRC) (2022) underscores the critical importance of food security during wartime. The ICRC emphasises that addressing food insecurity requires a multidisciplinary approach, considering how conflicts impact agricultural systems by destroying infrastructure and trade networks. According to the norms of international humanitarian law (IHL), the starvation of civilian populations as a method of warfare is prohibited, which can help mitigate the consequences of conflict.

Studies such as those by R.P.F. Guiné (2024) analyse the current challenges of food security in the context of global changes. This research discusses major problems facing agriculture, including climate change, geopolitical conflicts, and economic instability, which affect food production and distribution worldwide. The author also proposes strategies for improving food security, including sustainable agricultural development, technological innovations, and international cooperation. The work of A. Kozielec *et al.* (2024) examines the economic and social challenges arising from crises such as wars and economic shocks and the impact on food security. The article provides an analysis of food risk management strategies based on the experience of Polish agricultural enterprises during economic difficulties, particularly in the context of political instability.

Research by O.M. Pashchenko (2022) focuses on the legal aspects of ensuring food security under martial law. The article examines the main legal challenges in food security in Ukraine during wartime, particularly regarding the regulation of food production and distribution, as well as support for local communities and agricultural enterprises. The authors highlight the need to adapt national legislation to the new conditions caused by armed conflicts and stress the importance of synergy between state bodies and businesses in overcoming crises. Scholars also address mechanisms of legal support for food security, considering external and internal policy factors, and propose ways to improve legal tools for effective food security management during war.

The study by I. Bezhenar & O. Hryshchenko (2023) analyses the current state of farms in Ukraine and the development opportunities. The researchers highlighted the importance of farms in ensuring food security and the stability of the country's agricultural sector. E.-E. Halmaghi *et al.* (2023) explored the complex interconnections between food security and armed conflicts. The authors analysed how conflicts disrupt local agricultural practices, destroy food supply chains, and exacerbate food security challenges. Using data and examples from regions most affected by military actions, the researchers emphasised the need for sustainable solutions and structural measures to mitigate the negative consequences for affected communities.

S. Berezyuk *et al.* (2023) studied food security in wartime conditions, emphasising the challenges associated with maintaining the stability of the agricultural sector during war. The article analyses the impact of hostilities on agricultural production and food imports. Particular attention was paid to resource management issues in crisis conditions and the mechanisms for supporting food security proposed by the authors. The research findings indicate that the implementation of systemic measures at the state policy level can enhance the country's self-sufficiency in the agricultural sector. The monograph

by V.Yu. Urkevych *et al.* (2014) examined key aspects of Ukraine's agricultural policy through the lens of legal regulation, highlighting the interrelation between food security, land relations, and state governance in the agricultural sector. The authors focused on the challenges of legal regulation in the agricultural sector, particularly aspects of land reform, the creation of an effective agricultural cadastre, and the implementation of a land resource management system that contributes to food security.

Despite the contributions of Ukrainian and international researchers to the study of food security challenges, aspects of effective cooperation between state, local, and international organisations in overcoming food challenges at the community level remain insufficiently explored. Based on these gaps, the study aimed to analyse the impact of wartime conditions on food security in local communities, assess the adaptive capacity of different types of communities, and develop recommendations to enhance resilience. To achieve these objectives, the following tasks were identified: identifying key challenges of food provision in communities during the war; analysing the impact of agricultural, social, and economic policies on community recovery; and determining effective cooperation mechanisms to support food security in a regional context.

► Materials and methods

The study was conducted in 2024 across three communities located in different parts of Ukraine: Starosaltivska community (Kharkiv region), Mezhyvska community (Dnipropetrovsk region), and Kulykivska community (Lviv region). These communities were selected based on the distinct socio-economic situations and varying degrees of wartime impact. The first community, located in the front-line zone, consists of 10 settlements with a total population of approximately 8,000. The second, a transit community, has a population of 15,000 across six settlements. The third, a remote community, is a town with 25,000 residents and 18 surrounding villages. Each community presents a unique case that allows for a comprehensive assessment of the impact of wartime challenges on food security.

Data collection adhered to the provisions of the Law of Ukraine No. 2657-XII (1992) to ensure compliance with data collection and usage norms, as well as the protection of confidential information. This approach minimises potential risks to residents and businesses, particularly under martial law, while prioritising the safety of inhabitants and economic activities in the regions. Secondary data was collected from official statistical reports and humanitarian organisation records (International Committee of the Red Cross, 2022; 2024; UKRINFORM..., 2022; Derzhstat, 2024; Ministry of Agrarian Policy and Food of Ukraine, 2025). This provided an overview of food security levels in the studied communities and identified key issues and threats faced by residents.

The study incorporated both secondary source analysis and field surveys. A total of 300 respondents participated (100 from each community), selected through random sampling while considering the socio-demographic characteristics of the population. Surveys were conducted offline (through personal interviews) and online via Google Forms to streamline data collection and processing. Results were analysed using Microsoft Excel and the

Statistical Package for the Social Sciences (SPSS) for statistical evaluation. The survey consisted of 20 questions covering the socio-economic aspects of food security in the community, citizens' willingness to participate in self-organisation programmes, food resource availability, and satisfaction with the fulfilment of basic needs. A five-point scale was used to assess respondents' answers, where 1 meant "very dissatisfied/disagree" and 5 meant "very satisfied/agree". The questions concerned food availability, diet adequacy, sources of food supply (humanitarian aid, self-production, market purchase), and major difficulties in food provision (physical or financial inaccessibility of products, logistical problems).

The main part of the study was based on the field stage, during which primary data collection was carried out through a survey of residents. In addition, official reports and statistical data were analysed, providing comprehensive information on the state of food security in communities (Report for 2024..., 2024; Report of the Mezshiv..., 2024; Report of the village..., 2025). The respondent sample was formed to represent different social and age groups (youth, middle-aged, and elderly categories) in each community. The age of respondents ranged from 18 to 70 years. To ensure sample representativeness, representatives of all key population categories directly related to food security issues were included (local government officials, community initiative leaders, farmers, and residents). The survey was conducted mainly in field conditions, using personal interviews, telephone calls, and online forms.

The survey was conducted using mixed data collection methods, ensuring the broadest possible coverage of respondents and increasing the reliability of the obtained results. In particular, the following methods were used:

1. Personal interviews – this method was applied for data collection in frontline communities (Kharkiv region), where access to respondents was difficult but allowed for more detailed information through direct contact.

2. Telephone calls – used as the primary tool in transitional communities (Dnipropetrovsk region), where some respondents had access to communication but could not complete an online form.

3. Online questionnaires – this method was the most effective in remote communities (Lviv region), where most of the population had stable internet access.

The mixed approach ensured flexibility and adaptation to the specific conditions of each community, considering the level of infrastructure accessibility and the degree of impact of military actions. The author's developed

survey methodology was used for data collection, taking into account the specifics of the studied communities and the current challenges of martial law. The methodology included questions adapted to the realities of each community, considering geographical location, demographic composition, and economic situation. A particular feature of the methodology was the development of separate question blocks: food availability, assessment of basic product prices, the presence and effectiveness of humanitarian programmes, and the impact of changes on agricultural production. This approach provided more detailed information relevant to each community. Specifically, respondents answered questions about food supply, product shortages, and strategies used to address these issues at the community level. For statistical analysis of the results, a methodology was used that included a comparison of indicators within each community and between communities, using significance criteria such as Student's t-test for independent samples. This made it possible to assess the significance of changes in food security levels and identify factors that have the most significant impact on the situation in communities.

► Results

The survey made it possible to identify households' subjective assessments regarding food availability, the level of satisfaction of basic needs, and the main problems faced by residents of various regions of Ukraine, concerning food security indicators (Economist Impact, 2022). The obtained results not only reflect the current state of food security in communities but also allow for assessing the ability of local authorities and communities to adapt and recover in wartime conditions. At the same time, significant differences in food security levels across regions were identified. Local initiatives, particularly in tourism development, help enhance economic resilience during crises, but the effectiveness varies depending on available resources and specific regional circumstances (Bergström & Larsson, 2022).

The Starosaltivska community in the Kharkiv region faces a challenging food security situation. The survey results show that only 25% of respondents have constant access to food, indicating a high vulnerability of the local population to supply disruptions. The majority, or 54%, experience partial food availability, suggesting persistent but substantial food supply issues. Meanwhile, 22% report food as nearly unavailable, highlighting a critical shortage in certain parts of the community (Table 1).

Table 1. Survey results in the Starosaltivska community, Kharkiv region

Indicator	Percentage of Respondents (%)	Interpretation
Food is always available	25	Only a quarter of the population has consistent access to food
Food is partially available	54	Half of the respondents face supply disruptions
Food is unavailable	22	A quarter of the population experiences critical shortages
Main food source: humanitarian aid	66	Dependency on humanitarian aid is very high
Main food source: self-production	11	Production has declined due to hostilities
Main food source: purchases	27	Economic accessibility is limited due to high prices
Main food source: local production	30	Local production remains an important food source
Main food source: tourism and related industries	5	Hostilities and uncertainty significantly limit tourism infrastructure and local businesses

Source: developed by the authors

One of the main food sources is humanitarian aid, relied upon by 66% of respondents, indicating an extremely high dependence on external support. In wartime conditions, this poses a severe threat to sustainable food provision (Gerasymchuk & Gasukha, 2021). Only 11% of respondents cite the production as the primary food source, reflecting a decline in local agricultural production due to hostilities and worsening conditions for farming. Regarding economic accessibility, 27% purchase food, though high prices and delivery challenges significantly limit this option for most people. However, local production remains a vital food source for 30% of respondents, underlining the importance of developing the agricultural sector even in wartime conditions. Nonetheless, existing challenges, including high risks and resource shortages, prevent full food security in

the community. Additionally, only 5% of respondents rely on tourism as a food source. Given the ongoing hostilities and uncertainty, tourism infrastructure development is severely restricted, complicating additional income sources for residents and businesses. Thus, the community faces extraordinary difficulties in meeting basic needs, emphasising the necessity for comprehensive support and local production restoration to reduce reliance on external food sources. The survey results highlight the unprecedented challenges caused by hostilities and the need to enhance the quality and quantity of humanitarian aid, develop local production, and improve economic accessibility to stabilise the community's food situation. Indicators identified in the survey of residents of the Mezhyvska community in the Dnipropetrovsk region are presented in Table 2.

Table 2. Survey results in the Mezhyvska community, Dnipropetrovsk region

Indicator	Percentage of Respondents (%)	Interpretation
Food is always available	52	Half of the population has stable access to food
Food is partially available	43	Supply disruptions exist but are less pronounced
Food is unavailable	13	A significantly smaller portion of the population experiences critical shortages
Main food source: humanitarian aid	38	The level of dependence on humanitarian aid is moderate
Main food source: self-production	22	Production recovery is moderate but positive
Main food source: purchases	41	Economic accessibility is better than in frontline communities
Main food source: local production	45	Preserving a certain level of food security
Main food source: tourism and related industries	12	Remains limited and is not a significant food source

Source: developed by the authors

The food security situation in the Dnipropetrovsk region community is somewhat better compared to the frontline community in the Kharkiv region. The survey results indicate that 52% of the population has stable food access, a significant achievement, as half of the respondents do not experience supply disruptions. Compared to other communities, only 13% of respondents face critical food shortages, indicating less severe food security issues. A key factor is the recovery of local production. 22% of respondents report that the production has become a food source, which is a positive trend, though not yet sufficient to meet the entire population's needs. Unlike most communities, the economic accessibility of food in this region is significantly higher, as evidenced by 41% of respondents purchasing food. This demonstrates an improved economic situation and more affordable food

prices compared to frontline regions, where high costs significantly limit purchasing options.

Local production remains an essential food source for 45% of respondents, ensuring a certain level of food security. Tourism and related industries, despite the limited significance (12%), do not constitute a major food source, likely due to a relatively stable socio-economic situation that supports more traditional food sources. Overall, the Dnipropetrovsk region community demonstrates moderate recovery following economic difficulties, enabled by improved logistics, local production support, and increased economic accessibility. This significantly reduces reliance on external sources, including humanitarian aid, compared to frontline communities. Data obtained from the survey of residents in the Kulykivska community, Lviv region, are presented in Table 3.

Table 3. Survey results in the Kulykivska community, Lviv region

Indicator	Percentage of Respondents (%)	Interpretation
Food is always available	76	The majority of the population has consistent access to food
Food is partially available	22	Only a small portion faces disruptions
Food is unavailable	6	Very low level of critical shortages
Main food source: humanitarian aid	17	Minimal dependence on external aid
Main food source: self-production	51	A high level of local production ensures community food security
Main food source: purchases	36	A stable market contributes to food accessibility
Main food source: local production	56	Significant agricultural sector development
Main food source: tourism and related industries	34	Tourism infrastructure provides additional income sources, greatly impacting the local economy

Source: developed by the authors

In the Kulykivska community of the Lviv region, food security indicators are significantly better than in communities closer to the zone of active hostilities. 76% of respondents have constant access to food, indicating a high level of food security. Only 6% admit to experiencing a critical food shortage, which is a very low figure compared to other communities. This situation results from the stable functioning of the market and uninterrupted logistics. According to the survey data, 51% of respondents rely on the production, while the overall dependence on local production resources is 56%. This means that a large portion of the population is fully provided with food through active local production. This sector is an important factor in ensuring food security in the community. It is also worth noting the significant role of tourism. 34% of respondents highlight the contribution of the tourism infrastructure to food provision. With the increase in the number of internally displaced persons who contribute to the development of local businesses, the tourism sector serves as an additional income source for local enterprises, such as hotels, restaurants, and souvenir shops. This, in turn, ensures a steady flow of income, supporting access to food resources, particularly during crises and wartime. Thus, the Lviv region appears significantly more stable compared to other communities due to the development of local production and tourism, creating a resilient economy amid constant threats, thereby increasing food security for its population.

The survey conducted in three communities revealed varying levels of food accessibility, dependence on humanitarian aid, and the status of local food production. The situation in the frontline community (Kharkiv region) is the most challenging: a significant portion of the population faces disruptions in food supply, with nearly two-thirds of respondent's dependent on humanitarian aid, and local production is limited due to hostilities. This indicates a high risk of food insecurity and a substantial need for external assistance to support the population. In the Dnipropetrovsk region, the situation is better but still unstable: half of the respondents have stable access to food, yet a large portion still faces occasional disruptions. The restoration of local production and more efficient logistics is reducing dependence on humanitarian aid, though it still plays an important role. The Kulykivska community of Lviv region demonstrates the most favourable situation: most of the population has continuous access to food, a significant portion relies on local production, and dependence on humanitarian

aid is minimal. This suggests the resilience of this community to food crises and its ability to meet the needs of its population even under difficult conditions. Additionally, the role of tourism as a food source adds special value. This infrastructure supports overall economic stability, which is a decisive factor in reducing the risks of food insecurity.

Overall, the survey results indicate significant differences in food provision depending on geographic location and the level of impact of the war on communities. In frontline regions, urgent measures are needed to improve food security, including the development of local production, strengthening logistical chains, and adapting existing infrastructure to ensure access to food resources amid hostilities. This may involve engaging local entrepreneurs in the production of staple foods, creating mobile points for delivering humanitarian aid, and ensuring necessary resources even under conditions of limited access. It is also crucial to involve organisations in ensuring the safety of supply lines, as areas affected by hostilities may face serious obstacles to food delivery. The survey results allow for the collection of subjective assessments of food availability and changes due to hostilities. These assessments contribute to a deeper understanding of the needs of local communities and reinforce conclusions about the effectiveness of the aid provided. The results also confirm findings from other studies, particularly the importance of local initiatives in reducing dependence on humanitarian aid, which is relevant for all types of communities under different conditions.

Information from the surveys enables the evaluation of the impact of international organisations on improving food security, comparing the aid provided with the actual needs on the ground, and is supplemented by official data from the Reports of the State Statistics Service of Ukraine, which are published annually and contain vital information on agricultural production, food reserves, consumption levels, and the volumes of food imports and exports (Derzhstat, 2024). These reports serve as the main sources for analysing the agricultural economy at both national and local levels, and help monitor changes in food security levels (Law of Ukraine No. 2145-IX, 2022; Ministry of Agrarian Policy and Food of Ukraine, 2025). A comparison of the impact of the war on the production of major crops is presented in comparative Table 4, which shows indicators before 2022, when active hostilities began, and after. This allows for an assessment of how production volumes have changed during the war and how this affects food security in the communities.

Table 4. Comparison of major agricultural crop production indicators in communities before 2022 and after the start of active hostilities (2022-2024)

Crop	Starosaltivska community, Kharkiv region (tonnes)	Mezivska community, Dnipropetrovsk region (tonnes)	Kulykivska community, Lviv region (tonnes)
Wheat	5,000	5,500	4,800
Wheat (after 2022)	3,200	4,500	4,000
Corn	4,000	4,500	3,800
Corn (after 2022)	2,500	3,700	3,100
Sunflower	3,500	4,000	3,500
Sunflower (after 2022)	2,000	2,800	2,400
Potatoes	2,000	1,800	1,600
Potatoes (after 2022)	1,100	1,500	1,300
Vegetables	1,500	1,600	1,400
Vegetables (after 2022)	900	1,200	1,100

Source: developed by the authors

According to the comparison results, after the start of active hostilities (since 2022), there has been a significant reduction in the production of major crops in all communities. Specifically, in the Starosaltivska community of the Kharkiv region, wheat, corn, sunflower, potatoes, and vegetables production decreased by 20-40% compared to pre-war levels, indicating difficulties in food provision due to hostilities and infrastructure destruction. The Mezivska community of Dnipropetrovsk region showed smaller losses in production volumes, which may indicate a more stable situation due to the lower intensity of hostilities in the region and the preservation of significant production potential. In the Kulykivska community of Lviv region, a decrease in production is also observed, but the changes are less significant, which can be explained by the relative stability of the region, far from the zone of active hostilities. These data emphasise the importance of supporting and restoring local production to ensure food security, especially during wartime when reliance on external supplies may be limited.

The next phase of the study involved analysing information published on the official websites of the communities, where reports on food provision were posted (Report for 2024..., 2024; Report of the Meziv..., 2024; Report of the village..., 2025). This information included data on the availability of basic food reserves in three communities for different periods, including before 2022 and after the start of active hostilities. As a result of the analysis, information was collected on the available reserves of staple food products (wheat, corn, potatoes, vegetables), which allowed for an assessment of changes in these reserves in the communities before and after the start of active hostilities. Determining food reserves is crucial for ensuring food security, as it helps to understand how prepared a community is for situations where access to food may be restricted due to military actions. A quantitative comparison of the food reserves of major agricultural crops in the Starosaltivska community of Kharkiv region is presented in Figure 1.

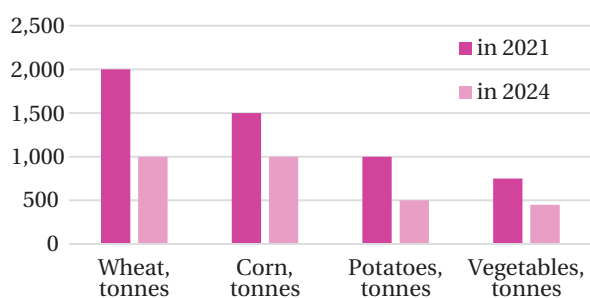


Figure 1. Indicators of food stock levels in the Starosaltivska community of Kharkiv region

Source: compiled by the authors based on Report for 2024 of the community police officers of the Starosaltiv territorial community (2024)

Figure 1 shows a significant reduction in food stocks, particularly wheat and corn, due to active combat operations. Wheat stocks have halved, while corn stocks have decreased by 40-50%. The situation is further complicated by the risks to agricultural enterprises due to combat activities, infrastructure damage, and landmining, which

hinder the preservation of food reserves. A quantitative comparison of food stock levels for key agricultural crops in the Meziv community of Dnipropetrovsk region is presented in Figure 2.

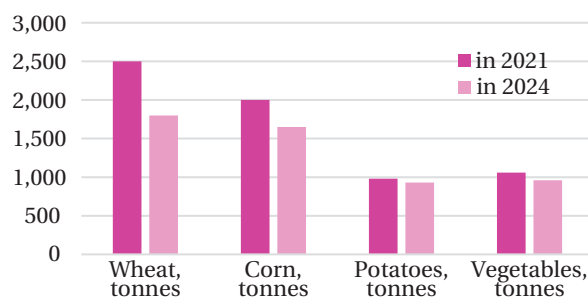


Figure 2. Indicators of food stock levels in the Meziv community of Dnipropetrovsk region

Source: compiled by the authors based on Report of the Meziv village head for 2023 (2024)

Although the situation with food reserves in the Meziv community of Dnipropetrovsk region is somewhat more stable compared to front-line territories, it still reflects the overall trend of decreasing stocks of essential products. Wheat stocks have decreased by 40-50%, and corn stocks have dropped by 30-40%. This indicates certain logistical problems and increased demand due to population displacement, though the situation has not yet reached a critical level. The analysis of agricultural crop production in the Kulykiv community of Lviv region is presented in Figure 3.

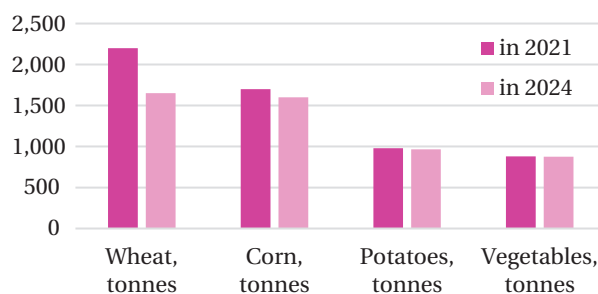


Figure 3. Indicators of food stock levels in the Kulykiv community of Lviv region

Source: compiled by the authors based on Report of the village head Liliya Bova on the work of the Kulykivska village council and its executive bodies for 2024 (2025)

In the Kulykiv community of Lviv region, changes in food stocks were less significant, with a 10% decrease, which suggests a lower intensity of crisis factors compared to front-line communities. However, the trend toward a reduction in food resources persists, likely due to disruptions in logistics and increased demand due to changes in the local market. Overall, the results of the analysis highlight the need to strengthen support for agricultural enterprises, particularly in communities located in high-risk zones. It is also essential to develop rapid food recovery plans, particularly through collaboration between local authorities, humanitarian organisations, and the enterprises themselves.

The next source of information for the study came from official UN resources, particularly the WFP and ICRC. These organisations actively publish reports and analytical materials on official websites, particularly on the WFP portal and the information pages of the International Committee of the Red Cross (2022; 2024). The data includes information on the amount of aid provided, its distribution directions, and cooperation mechanisms with local communities and authorities. The UN and ICRC use data from field surveys, local population interviews, and reports from local authorities to identify communities with the greatest need for food and other resources. The needs assessment is based on criteria such as the number of internally displaced persons, the level of provision of basic food products, the condition of local infrastructure, access to medical services, and proximity to active combat zones.

Priority is given to communities that have found themselves in a humanitarian crisis zone, especially those located in front-line areas or temporarily occupied territories. The contribution of these organisations includes

providing basic food products, which typically include cereals, legumes, vegetable oils, and baby food. Since the beginning of active combat in 2022, the World Food Programme (2023) has provided food to more than 3 million people in Ukraine, including in the most remote communities. The ICRC, for its part, provides targeted assistance in the form of food packages, drinking water, medicines, and essential items (Useful information for..., 2022).

Collaboration with local farming enterprises is an important element of these organisations' work (Nivievskiy *et al.*, 2021; Foote, 2022). By involving local producers, not only are logistics costs reduced, but the local economy is also supported. In the contribution of international organisations to ensuring food security in communities under military action, significant importance lies in cooperation between state and civil structures, as well as the direct involvement of international organisations in solving humanitarian issues. As shown in Table 5, the main mechanisms of assistance are food supplies, stock creation, and providing targeted support to the most vulnerable categories of the population.

Table 5. Contribution of international organisations to providing food security to communities (2022-2024)

Organisation	Starosaltiv community of Kharkiv region	Mezhiv community of Dnipropetrovsk region	Kulykiv community of Lviv region	Total number of aid recipients (persons)	Main types of aid
WFP	25,000	18,000	10,000	53,000	Cereals, oil, baby food
ICRC	30,000	20,000	12,000	62,000	Food, drinking water, medicines

Source: compiled by the authors based on Report for 2024 of the community police officers of the Starosaltiv territorial community (2024), Report of the Mezhev village head for 2023 (2024), Report of the village head Liliya Bova on the work of the Kulykivska village council and its executive bodies for 2024 (2025)

Data obtained from official UN and ICRC resources confirm the significant impact of international aid on ensuring food security in Ukrainian communities. The involvement of international organisations remains critically important for overcoming the food crisis, especially in communities affected by combat operations. However, for long-term stability, it is necessary to expand cooperation with local producers, optimise logistics, and actively involve local communities. The results of the study demonstrate that food security in communities depends significantly on various interconnected factors: local production, food stock volumes, the efficiency of local self-government bodies, and international humanitarian support. In the context of ensuring food security during wartime, it is important to focus on the potential for developing certain sectors, such as tourism and renewable energy. However, at present, in the context of the Kharkiv region, particularly in front-line communities, the aspect of tourism development seems less relevant. Despite being a useful strategy for reviving economic activity in more stable regions, tourism is not a priority given the current military threat. Therefore, to improve food security, it is worth focusing on the development of local production and infrastructure adapted to the realities of war. Meanwhile, in restoring energy sources, particularly through green energy, there is significant potential to strengthen the resilience and energy independence of communities in the post-war period. The analysis of statistical data, information

from local authorities, and international organisations has confirmed both the significant challenges and the adaptive potential of communities in wartime conditions.

► Discussion

The results obtained point to the importance of an integrated approach to ensuring food security under current challenges. The study conducted helps to better understand the contemporary challenges in food security, especially in crisis situations such as war. Consistency with the conclusions of other researchers confirms the relevance of the topic. W. Anderson *et al.* (2021) examined the impact of military conflicts on the exacerbation of food insecurity due to drought in Sub-Saharan Africa between 2009 and 2019. The authors found that conflicts significantly increase the vulnerability of agriculture and hinder effective responses to natural disasters, such as drought, complicating the achievement of food security in such regions. Statistical data and models were used for the study, which allows for analysing the interaction between conflicts and climate issues.

Unlike the current study, which analyses the situation with food security in Ukraine during the war, W. Anderson *et al.* (2021) examined the effects of drought on food security in Africa. The new study focuses on community responses to food issues during war, while the authors examine the broader regional context. However, both studies emphasise how external crises, whether caused by climate factors

or conflicts, exacerbate food insecurity. The analysis of the obtained data showed that the location of agricultural areas relative to active combat zones has a significant impact on agricultural sector productivity. In areas closer to the conflict line, there is a significant decrease in yield, food stock volumes, and overall food security levels (Drobitko & Alakbarov, 2023). This phenomenon can be explained by direct losses in infrastructure, restricted access to resources and crop fields, and the threat to human capital.

In the study by O. Shebanina *et al.* (2023), the role of environmental insurance in restoring ecological stability and resilience in Ukraine after the war is explored. The authors highlight the need for the implementation of sustainable environmental practices, particularly in the agricultural sector, and the use of insurance as a tool to mitigate risks associated with environmental disasters during the recovery process. The study emphasises the importance of such strategies for ensuring ecological resilience and supporting continuous development. Some parallels can be drawn between this research and the current one, as both focus on post-war recovery; however, this article's emphasis is on food security, its provision in wartime, particularly the role of humanitarian aid and local production. In contrast to O. Shebanina *et al.*'s work, which focuses on restoring ecological resilience through the insurance mechanism, my study concentrates on operational measures to meet the population's food needs in the context of ongoing combat operations.

In the study by A. Kliuchnyk *et al.* (2023), public management and state administration in territorial communities in Ukraine during the war are discussed, as well as the role these processes play in the post-war recovery of the country. The primary objective is to uncover the changes in the functioning of local government bodies and the interaction with military administrations after the introduction of martial law, which includes the transformation of the powers of village, settlement, and city councils since February 24, 2022 (Kryvenko, 2024). The authors also propose two criteria for the distribution of powers during martial law. According to findings, the described governance model and the interaction of government bodies are crucial for the recovery of territorial communities in the post-war period.

Compared to the current study, which focuses on food security during the war, parallels can be made regarding the need to adapt local structures to new conditions. Just like in public management research, effective governance is of heightened importance in wartime, but here, the focus is on ensuring food supply for the population (Matviishyn & Harbarynina, 2023). However, the key difference lies in the research direction: the new study focuses on specific aspects of food security, while A. Kliuchnyk *et al.* (2023) focus on general governance issues during and after the war. At the same time, as highlighted by the authors, effective governance and reforming local government bodies are critical for Ukraine's recovery after the war, which also directly impacts the stability of food security in the communities.

Analysing the results of B. Kemmerling *et al.* (2022) in the context of this study reveals several key aspects. The results of this research show that military actions significantly affect food security through four main mechanisms:

infrastructure destruction, population displacement, resource control by opposing parties, and the deliberate use of hunger as a weapon. The current study confirms these trends, as there is a significant impact from the destruction of logistics chains and reduced access to food resources due to the occupation of some territories and the destabilisation of local production in frontline and transitional communities in Ukraine. The conclusions also align regarding the importance of humanitarian aid in ensuring the survival of the population in the context of military conflict. As noted in the study by B. Kemmerling *et al.*, the effectiveness of international support depends on considering local realities and capacities. Similar conclusions are drawn in the current study, which stresses the role of humanitarian aid in frontline communities and the importance of integrating international efforts with local initiatives. However, some discrepancies exist. The study by B. Kemmerling *et al.* (2022) focuses on global aspects and systemic challenges for humanitarian aid, whereas this study emphasises national specifics: the influence of military administration, the adaptation of local governments, and the economic activity of individual communities. This highlights the need for more detailed examination of regional peculiarities in international studies.

The study by A. Adelaja & J. George (2019), which examines the impact of armed conflicts on agriculture in Nigeria, bears significant parallels with the research on the agricultural sector in Ukraine during the war. The key aspect is examining how conflicts destroy not only infrastructure and production resources but also lead to long-term socio-economic consequences, such as reduced agricultural productivity, lack of market access, and disruption of supply chains (Boiko *et al.*, 2024; Dankevych *et al.*, 2024). These effects are extremely important for comparing the situation in Ukraine, where the war also has similar effects on the agricultural sector. In Ukraine, as in Nigeria, agricultural producers face challenges such as decreased yields and limited access to markets, which worsens the food security situation. However, there are some differences: in Nigeria, conflicts caused by terrorist groups limit the state's ability to influence the recovery of the agricultural sector, whereas in Ukraine, humanitarian aid and state support measures have been organised.

Specifically, one key aspect of this study is the analysis of the role of small farmers in Ukraine, the ability to adapt and recover, which directly impacts local-level food security. The works of the authors mentioned above also emphasise the importance of local initiatives in supporting stability, which allows for a comparison of the role of small producers in Ukraine with similar processes in Nigeria. Although the situation in Ukraine differs significantly from that of Nigeria, the study by A. Adelaja & J. George (2019) holds valuable parallels for the current analysis. Both studies highlight the impact of war-related challenges on agriculture, leading to similar problems, including reduced yields and disruption of supply chains. In Ukraine, despite differences like the conflict, the role of local communities in recovering the agricultural sector and ensuring food security is critical.

Also crucial is the issue of the impact of global trends on the local level. The conclusions of A.V. Revkova (2023) emphasise the need for a multi-level system of support for

community development, especially in the context of crisis phenomena and challenges. In this context, the integration of environmentally sustainable practices into production processes and infrastructure modernisation, which ensures not only economic stability but also improves the quality of life at the local level, is of great importance (Berezyuk *et al.*, 2023). The role of communities in Ukraine, particularly under current socio-economic challenges, is becoming strategically significant, acting not only as main centres for supporting food security but also as key agents of change, capable of adapting to new conditions and carrying out essential functions to ensure sustainable development locally (Local economic development..., 2022).

The identified patterns indicate the need to strengthen support for local producers through legislative initiatives, financing programmes, and innovation implementation (Kryvokhyzha *et al.*, 2023). Meanwhile, further research should focus on examining the interaction of local and global factors influencing food security. Special attention should be given to analysing the successful experiences of other countries and the possibilities of adapting them to Ukrainian realities (UN Report..., 2022). In Ukraine, a legislative framework is being developed to improve food security, particularly through improving regulatory acts related to agricultural activities and stimulating domestic food production (Law of Ukraine No. 8370, 2011; Order of the Cabinet of Ministers of Ukraine No. 327-r, 2022; Order of the Cabinet of Ministers of Ukraine No. 684-r, 2024).

The study by K.E. Agboklou *et al.* (2024) examines the impact of armed conflicts on achieving Sustainable Development Goals (SDGs), particularly on food security. It focuses on the general impact of war on access to food resources. This research aligns with the theme of ensuring food security in wartime but focuses on the broader context of SDGs, whereas this study highlights specific measures for supporting food security during conflicts. The study by A. Alnabih *et al.* (2024) analyses the impact of war on food security and body weight loss among the population of Gaza. The authors focus on the physical and social consequences of food instability in the context of armed conflict. This study relates to the theme of ensuring food security in conflict zones, but while A. Alnabih *et al.* emphasise health and weight loss as a result of food shortages. This study focuses on operational measures aimed at meeting the food needs of the population during wartime.

The work by M. Koc *et al.* (2007) analyses the impact of war and sanctions on food security in Iraq. The authors focus on changes in the availability of food for the civilian population, which correlates with food security issues during wartime, but place more emphasis on global aspects and political factors. The work by C. Isendahl & S. Barthel (2018) examines the integration of archaeology and history to study urban food security, with an emphasis on a long-term and cross-cultural perspective. This contextualises food systems in cities. Unlike the work focused on the impact of war on food security, this research highlights the importance of historical and cultural factors for the sustainable development of food systems in urban settings.

The study by M. Khakpour *et al.* (2019) explores factors that promote or hinder food security for Afghan refugees in Karachi, Pakistan. This study emphasises the specific challenges faced by refugees in urbanisation and

limited access to resources. Unlike research focused on wars and humanitarian crises, this study examines food security issues among refugees in peaceful settings, specifically considering the socio-economic barriers. The study by M.E. Margulis (2017) analyses the history of food security in the context of multilateral trade negotiations. The research focuses on how food security was not adequately addressed during global economic agreements and discusses the lack of focus on its importance in international trade strategies. This contrasts with the current study, which addresses more practical aspects of food security during armed conflicts and the impact on the population in war zones.

The study by C. Eigenbrod & N. Gruda (2014) examines the role of horticultural crops in ensuring food security in urban areas, particularly the contribution to food supply stability in cities. This research focuses on using urban spaces for vegetable cultivation, contributing to the self-sufficiency of urban communities. In the works by S.K. Wegren (2023) and S. Bhowmick (2018), food security issues in the context of global challenges, particularly food crises, are explored. S.K. Wegren focuses on the political aspects that lead to global food crises, emphasising the importance of policies to ensure stability in the food sector. In turn, S. Bhowmick highlights the role of international organisations in shaping food security strategies in conflict zones. Both studies complement the current research on food security but differ in scale and perspective.

The research by A.W. Weldegiargis *et al.* (2023) and J.E. Sullivan & D. Kamensky (2024) analyses various aspects of the impact of war on security in specific contexts. The first study focuses on the impact of the armed conflict in Tigray (Ethiopia) on household food security, highlighting how the war exacerbates food instability. The second study, although not directly related to food security, examines violations of international law through Russia's attacks on Ukraine's energy infrastructure, which, in turn, has a huge indirect impact on food security due to disruptions in energy supply for food production and distribution. However, both studies share a common focus on the negative consequences of military actions for the stability and provision of basic needs for the population. Thus, the results of the analysis align with general trends found in the academic literature and confirm the importance of the local level in addressing food security issues. At the same time, there remain several open questions, particularly regarding the resilience of production systems in crisis conditions, which require further research.

► CONCLUSIONS

The conducted study determined that the impact of the war on Ukraine's agricultural sector leads to significant changes in the development of rural communities and food security. It was found that the most negative impact is observed in regions close to the combat zone, where there is a significant decrease in crop yields and access to basic resources such as water and fertilisers. Overall, the study confirmed the importance of integrating local initiatives into the recovery of agriculture, particularly through the improvement of infrastructure and the application of sustainable environmental practices. An important factor is the development of non-traditional sources of income,

including tourism, which shows significant potential even in regions remote from the conflict. For example, in a community in Lviv Region, 34% of food is provided through the tourism infrastructure, creating additional opportunities for the local economy. Comparing with international studies allowed concluding that similar challenges are relevant to other countries experiencing conflicts. However, in the Ukrainian context, the development of tourism and its integration into food strategy could play a key role in solving food security issues at the local level.

The results of the study demonstrate a significant impact of the war on Ukraine's agricultural sector and varying levels of food security in three communities, depending on the proximity to the fighting. In the frontline community (Kharkiv Region), only 25% of the population has stable access to food, and 66% rely on humanitarian aid, while the yield of major crops, such as wheat, fell from 5,000 tonnes to 3,200 tonnes. In the transitional community (Dnipropetrovsk Region), half of the respondents reported stable access to food, and wheat yields decreased by 18%, from 5,500 tonnes to 4,500 tonnes. The remote community (Lviv Region) shows the best indicators: 76% have constant access to food, 51% rely on the production, and wheat yield losses are the smallest, with only a 16% decrease (from 4,800 tonnes to 4,000 tonnes). This indicates a direct dependence of food security on the intensity of hostilities, the level of local production, and access to logistics.

Analysis of data on reduced food stocks indicates a significant impact of military actions on food security in the studied communities. The largest losses are observed

in the communities of Kharkiv and Dnipropetrovsk regions, where wheat stocks have halved, and corn stocks have decreased by 40-50%, significantly weakening food provision capabilities. Stocks of potatoes and vegetables have also decreased, especially in the frontline zone, where enterprises face additional risks: shelling, minefields, damage to infrastructure, and warehouse buildings. Even in the rear area of Lviv Region, a reduction in food stocks by 20-30% indicates logistical breakdowns and the impact of internal population displacement.

A limitation of the study is the insufficient amount of data to analyse all regions of the country, as some territories remain inaccessible due to military actions, as well as the limited exploration of the impact of specific political and social factors on agriculture during the conflict. In the future, to improve the results of the study, it is important to pay more attention to a detailed analysis of the role of governments and international organisations in supporting rural communities, as well as exploring opportunities for developing new technologies to restore damaged agricultural territories.

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Забезпечення продовольчої безпеки в громадах в умовах воєнних викликів

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► **Анотація.** Метою дослідження був аналіз продовольчої безпеки місцевих громад України в умовах воєнних викликів, з акцентом на впливі активних бойових дій на продовольчі ресурси, рівень виробництва, запаси та гуманітарну підтримку. Додатково, аналіз врахував вплив туризму, особливо у транзитних і віддалених громадах. У процесі дослідження було використано дані статистичних звітів Державної служби статистики України, інформацію від органів місцевого самоврядування, міжнародних організацій, таких як Всесвітня продовольча програма та Міжнародний комітет Червоного Хреста, а також результати опитування громадян трьох громад: Харківської, Дніпропетровської та Львівської областей. Опитування охоплювало питання щодо доступності продовольства, основних потреб у базових харчових продуктах і оцінки гуманітарної допомоги. Застосовані методи анкетування через онлайн-форми та телефонні опитування населення, а також запити на публічну інформацію до органів місцевого самоврядування. Аналіз показав, що прифронтowa громада (Харківська область) стикається з найбільшими викликами: 65 % респондентів повідомили про значний дефіцит базових продуктів, порівняно з 40 % у транзитній (Дніпропетровська область) та 20 % у віддаленій громадах (Львівська область). Дані з офіційних джерел підтвердили, що після початку повномасштабних бойових дій у 2022 році на території України обсяги виробництва основних сільськогосподарських культур знизилися на 40 % у прифронтovій громаді, тоді як запаси продовольства виявилися критично низькими. Міжнародна допомога відіграє важливу роль у стабілізації ситуації, особливо шляхом забезпечення базових харчових потреб і розвитку стійкості громад. Результати дослідження підкреслюють необхідність посилення взаємодії між територіальними громадами, державними установами та гуманітарними організаціями, а також вдосконалення стратегій управління продовольчими ресурсами. Крім того, отримані дані акцентують на важливості врахування регіональних особливостей для ефективного планування гуманітарної підтримки та відновлення економічної діяльності громад.

► **Ключові слова:** гуманітарна допомога; територіальні громади; опитування мешканців; воєнний стан



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Problems and prospects of food security in the agro-industrial complex of Kyrgyzstan: Economic analysis and recommendations

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► **Abstract.** The study focused on analysing the state of the agro-industrial complex of the Kyrgyz Republic to develop measures for its modernisation in the context of ensuring food security. An analytical approach was used, which included a systematic analysis of statistical data on agriculture, animal husbandry, and the food industry. The main focus was on investigating the dynamics of agricultural production, including the growth of livestock and crop production, and analysing current trends in food processing and production. The study identified the main challenges affecting food security: climate change, price instability in global markets, dependence on imports, and insufficient infrastructure. Challenges in product processing, storage, and farmer financing were identified alongside encouraging growth in food production, emphasising the need to strengthen the national agro-industrial sector. The analysis revealed opportunities for agricultural diversification, technological innovation, and more efficient use of water and land resources through cooperative development. Key priorities include establishing regional logistics hubs, upgrading storage and processing facilities, and expanding government support programmes to create a more resilient agricultural system. The need for coordination with international organisations such as the United Nations and the World Bank to implement sustainable development strategies, including the sustainable development goals, was highlighted. The paper included an exhaustive examination of the present circumstances and pragmatic

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suggestions intended to enhance Kyrgyzstan's food security amid global difficulties. The results obtained can be used by government agencies, agricultural enterprises, and farmers to develop strategies for the development of agriculture, increase its sustainability, and ensure the country's food independence

► **Keywords:** agriculture; sustainable development; resource management; technological modernisation; public policy

► Introduction

Food security represents a critical challenge for Kyrgyzstan due to the country's heavy reliance on food imports and limited domestic agricultural capacity. The nation's vulnerability stems from its dependence on external suppliers, constrained resources, and exposure to global disruptions, including climate variability and geopolitical tensions that can disrupt supply chains and affect food availability. Agriculture forms the backbone of Kyrgyzstan's economy, yet the sector struggles with significant structural weaknesses. Low agricultural productivity, inadequate mechanisation, and restricted access to modern farming technologies limit the country's ability to achieve food self-sufficiency. These challenges are compounded by volatile global commodity prices that create uncertainty for both producers and consumers, making food affordability and access unpredictable. The complexity of food security extends beyond simple availability to encompass accessibility, stability, and nutritional quality of food supplies. Environmental considerations including soil quality, water resources, and climate patterns further influence the agricultural system's capacity to meet population needs. The country needs strategic planning that considers both immediate food security concerns and long-term sustainability goals. This includes investing in agricultural modernisation, developing resilient supply chains, and creating policies that support both producers and consumers while building the foundation for a more self-reliant food system.

A multitude of studies exist on food security and the agro-industrial complex, enhancing comprehension of the challenges and opportunities within this critical domain. Thus, Z.A. Musarova & C.U. Adamkulova (2023) emphasised the importance of developing local production and the transition to more sustainable agricultural technologies, which is particularly relevant for countries with vulnerable agricultural sectors. In turn, the study by N. Khan *et al.* (2021) contended that addressing the food crisis necessitates the establishment of a governmental programme to subsidise and train local producers, hence enhancing agricultural yields and sustainability.

S.K. Patel *et al.* (2020) stressed that in order to ensure food security, it is important not only to develop the agricultural sector, but also to improve infrastructure, which is a key factor in ensuring equal access to food for all segments of the population. V. Kozhogulova *et al.* (2023) revealed the most important problems in the field of state regulation of agriculture in Kyrgyzstan, where significant government investments in the agro-industrial complex often do not lead to expected results due to insufficient coordination between government agencies and the lack of a long-term strategy.

L. Hao *et al.* (2022) emphasised the important role of foreign trade and international economic relations in ensuring food security, pointing out that the opening of new

markets and the improvement of trade relations can become a significant tool for solving food security problems. G.S. Malhi *et al.* (2021) examined the impact of climate change on agricultural production and focused on the fact that agro-climatic conditions require adaptation to new challenges such as droughts and sudden temperature changes, which seriously affect agricultural sustainability and food security.

S.S. Hasan *et al.* (2020) identified the problem of inefficient use of agricultural land. They found that many farmers do not use the land at full capacity, which reduces the overall contribution of agriculture to the country's economy and leads to the irrational use of land resources. S.R. Semenov & N.S. Semenov (2024) showed that agrarian reforms in Kyrgyzstan, although they brought some improvements, still did not solve the problems of food security sustainability in the long term. They suggested developing risk management systems and investing in research aimed at identifying new ways to overcome agricultural problems.

H. Feng *et al.* (2020) highlighted the need to improve food chains, pointing out that many food security issues relate not only to production, but also to logistics and product distribution, which requires significant efforts to improve infrastructure and logistics in the agro-industrial sector. Ultimately, the study by C. Ene (2020) examined food security issues from the perspective of international trade. The researcher suggested that countries can significantly improve their food security by concluding strategic trade agreements with neighbouring countries, which reduces dependence on external factors and increases the stability of food supplies.

Notwithstanding extensive research on food security, certain aspects within the agro-industrial complex necessitate additional investigation. Inadequate attention has been paid to the methods of governmental support for the agriculture sector to enhance food security. Insufficient emphasis has been directed towards the sustainable management of land and water resources, considering their constraints and evolving climate circumstances. The problem of adaptation of farms to economic challenges, such as price fluctuations and technological lag, also remains poorly investigated.

The study aimed to formulate recommendations for enhancing the sustainability of food security within Kyrgyzstan's agro-industrial complex. The study intended to analyse the current status of food security in Kyrgyzstan, evaluate the efficacy of existing governmental support programmes for the agro-industrial sector, and assess their impact on food sustainability.

► Materials and methods

The primary emphasis was on analysing the condition of the agro-industrial complex of the Kyrgyz Republic, its influence on national food security, and evaluating the

principal reasons constraining the industry's development. The study used a systematic analysis of statistical data provided by the National Statistical Committee of the Kyrgyz Republic (n.d.). The main sources of information were data for 2020-2024, including agricultural production volumes, food industry indicators, and macroeconomic indicators. These data helped to determine the dynamics of production and identify key trends and changes in the agro-industrial sector. Particular emphasis was placed on the examination of categories including the production of meat, milk, eggs, grains, vegetables, fruits, and industrial crops.

To evaluate food security in Kyrgyzstan, researchers created visual representations through charts and data displays to track agricultural changes and pinpoint regions most at risk. The study examined key indicators such as the share of agriculture in Kyrgyzstan's gross domestic product (GDP), livestock and crop production, and food production. The study also examined Kyrgyzstan's international agricultural trade patterns, measuring both incoming and outgoing product flows to understand the country's reliance on foreign food sources and identify opportunities for increased exports. Researchers further investigated how well citizens' incomes could support their food purchases, providing insights into food accessibility and how price fluctuations affect what people can afford to buy.

When analysing the data, special attention was paid to external and internal factors affecting food security. Climate changes, including their impact on crop yields, and infrastructural constraints such as the lack of up-to-date storage and processing systems were considered. These variables were analysed regarding the availability and stability of food supply, a crucial element of comprehensive food security. The study performed a comparative analysis of Kyrgyzstan's agro-industrial complex alongside sophisticated and comparable nations, including the Netherlands, Israel, the USA, Japan, and Uzbekistan.

To develop the recommendations, a forward-looking analysis was used, considering national development strategies such as the National Development Programme of the Kyrgyz Republic until 2026 (2021), and global benchmarks presented by Sustainable Development Goals (n.d.). The study advocated strategies to implement advanced technology, including precision agriculture, soil monitoring systems, and efficient water resource management. The efficacy of these strategies was assessed for their influence on the sustainable growth of agriculture and the national food system. The Programme for the Development of Agricultural Cooperation in the Kyrgyz Republic for 2023-2027 (Resolution of the Cabinet of Ministers of the Kyrgyz Republic No. 41, 2023) was examined, focusing on bolstering farmers' groups, enhancing their competitiveness, and incorporating small producers into agro-industrial chains.

An important element of the methodology was the assessment of the role of government support and international cooperation. Measures aimed at improving the financing of farmers, developing cooperatives and stimulating the processing of agricultural products were investigated. In addition, the study considered the possibilities of agricultural diversification, such as the cultivation of export-oriented crops, which will increase the competitiveness of the Kyrgyz Republic in international markets.

► Results

Food security represents a cornerstone of state stability and sustainable development, encompassing economic, social, environmental, and political dimensions that determine a nation's capacity to ensure adequate, high-quality, and affordable food for its entire population. As globalisation, climate change, and economic crises intensify, food security has evolved from a domestic policy concern into a critical international security issue (Vågsholm *et al.*, 2020). At its core, food security requires states to guarantee sufficient food products that satisfy both quantitative and qualitative population needs while maintaining resilient food supply chains that prevent food crises. This multifaceted challenge demands comprehensive approaches that address production capabilities, distribution networks, economic accessibility, and nutritional adequacy. The interconnected nature of modern food systems means that disruptions in one area can cascade across entire regions, making food security a shared responsibility that transcends national boundaries. Food security encompasses four key components: accessibility, affordability within purchasing power, supply stability, and food quality (O'Hara & Toussaint, 2021).

Food availability refers to the enough quantity of items produced domestically or imported to satisfy the population's demands. In developing economies like Kyrgyzstan, food availability is intricately connected to the agriculture sector, which predominantly serves as the primary source of food supply. However, the situation may be complicated by low productivity, high import costs, and unstable harvests. Accessibility within the limits of purchasing power encompasses the economic aspect of food security. The problem is that even with enough food, not every citizen can afford the necessary amount of food due to low incomes or inequality in the distribution of wealth (Pokhrel, 2020).

The stability of food supplies means the ability to maintain uninterrupted food supplies over a long period of time, regardless of seasonal fluctuations, natural disasters, or external economic shocks (Davis *et al.*, 2021). This is an important aspect for countries with limited natural resources, such as Kyrgyzstan, where the role of foreign trade and imports is invaluable. The quality of nutrition consists in providing the population not only with the quantity of products, but also with their diversity, nutritional value, safety, and compliance with relevant health requirements. It is important that food not only meets energy needs, but also provides the body with all the necessary vitamins, minerals, and trace elements. Food security is a complex notion that includes both the production and the economic accessibility and stability of the food supply. In the face of global challenges and internal instability, states must not only solve production problems, but also build effective distribution systems, resource management, and sustainable agricultural development. For Kyrgyzstan, with its dependence on external supplies and vulnerability to natural risks, food security is becoming the foundation of social well-being and economic stability.

The agro-industrial complex serves as the cornerstone of global food security by managing the production and processing of agricultural products. Its operational

efficiency determines food availability, economic stability, and population welfare across nations. Contemporary challenges including climate change, demographic expansion, and geopolitical tensions have amplified the sector's economic significance (Viana *et al.*, 2022). Advanced economies demonstrate this principle effectively. The United States, Germany, France, and Japan operate sophisticated agro-industrial systems characterised by extensive mechanisation, cutting-edge technologies, and intensive cultivation practices. Conversely, developing nations encounter substantial obstacles in agricultural development. Countries such as India, Pakistan, Kenya, and Uzbekistan struggle with productivity limitations, restricted technological access, and heavy reliance on imported food and agricultural inputs. Traditional farming methods predominate in these regions, where manual labor and basic mechanisation constrain production capacity and economic growth (Da Silveira *et al.*, 2021).

Stable food production reduces dependence on imports, reducing vulnerability to external shocks such as price fluctuations in global markets or trade restrictions. In addition, an efficient agro-industrial complex can become an export driver, providing an influx of foreign exchange and contributing to economic growth (Garcia *et al.*, 2020). The use of digital farm management systems, biotechnologies and precision farming methods can significantly increase yields and reduce the environmental burden. Droughts, floods, and other natural disasters require technology adaptation and the transition to sustainable farming practices (Shang *et al.*, 2021). In addition to its industrial and economic role, the agro-industrial complex performs an important social function, providing employment and income for a significant part of the population, especially in rural areas. The sustainable development of agricultural production contributes to reducing poverty, improving living standards and improving the social climate. The generation of employment in the agricultural sector is crucial for mitigating migration from rural areas to urban centres and abroad, hence preserving population distribution equilibrium (Laurett *et al.*, 2021).

The efficient operation of the agro-industrial complex is unattainable without a meticulously formulated government strategy. This includes farm subsidies, support for innovative technologies, infrastructure development, and easier access to credit resources. National and international level programmes such as Sustainable Development Goals (n.d.) emphasise the need to modernise the agricultural sector and introduce sustainable production methods to ensure global food security. The agro-industrial complex has significant potential for sustainable development. Improving the efficiency of resource management, improving logistics and developing processing capacities can not only increase production volumes, but also reduce losses at all stages of the food chain. The variety and quality of products also play an important role, as compliance with international standards opens up opportunities for integration into global markets.

The agro-industrial complex of Kyrgyzstan constitutes a vital sector of the economy, contributing substantially to GDP and serving as the primary source of employment for over 60% of the rural populace (National Statistical

Committee of the Kyrgyz Republic, n.d.). Agriculture, traditionally the backbone of the country's food system, faces a number of structural problems, such as low levels of mechanisation, insufficient use of innovative technologies, limited access to financial resources, and inefficient infrastructure. The agro-industrial complex mostly comprises small and medium-sized farms that generate the majority of agricultural goods; nevertheless, their operations are frequently constrained by inadequate productivity and antiquated farming techniques.

An increase in domestic production helps to reduce dependence on imports, which makes the country less vulnerable to external economic shocks, such as fluctuations in world prices for agricultural products and logistical problems. In addition, improved productivity helps to improve the quality of food products, providing the population with a more stable and affordable food supply. To achieve sustainable growth, it is necessary to solve existing problems, such as upgrading agricultural technologies and improving the infrastructure for storing and processing products (Fig. 1).

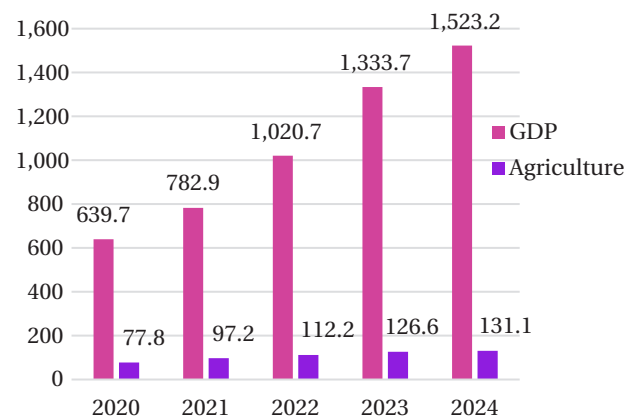


Figure 1. Share of agriculture in Kyrgyzstan's GDP for 2020-2024, billion KGS

Source: developed by the authors based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

Agriculture continues to be a significant sector of the Kyrgyz economy; however, its proportion in the GDP composition is declining. Despite the increase in absolute agricultural production from KGS 77.8 billion in 2020 to KGS 131.1 billion in 2024, the country's total GDP is growing at a faster pace. This signifies structural transformations in the economy, wherein the significance of alternative sectors, such as industry and services, is increasing. Nonetheless, the steady advancement of the agro-industrial complex is essential for food security and economic stability, particularly given the significant employment of the rural populace in this sector.

The most common industries are crop production (production of wheat, corn, potatoes, vegetables, and fruits) and animal husbandry (breeding of cattle, sheep, and goats). Despite the variety of agricultural products, most farmers are self-sufficient, which limits their participation in the market economy and makes it difficult to develop processing capacities. Table 1 shows the volume of livestock production for all categories of farms.

Table 1. Livestock production in Kyrgyzstan for 2020-2024

Year	2020	2021	2022	2023	2024
Cattle and poultry for slaughter, thous. t	401.2	428.9	441.2	448.1	459.7
Raw milk, thous. t	1,668	1,699	1,734.1	1,777.6	1,823.8
Eggs, million units	562	564.2	607.9	685.7	790.3
Wool, thous. t	13.1	13.1	12.9	12.9	13.2

Source: developed by the authors based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

Table 1 illustrates a favourable trend in the primary indicators of livestock output in Kyrgyzstan, but with minor changes in specific categories. Meat production grew steadily from 401,000 tonnes in 2020 to 460,000 tonnes in 2024, reflecting the expansion of meat farming. The volume of raw milk production also shows steady growth, increasing from 1,668 thousand tonnes to 1,824 thousand tonnes, indicating an improvement in

the conditions of keeping and feeding livestock. Particularly noteworthy is the growth in egg production, which increased by more than 40% – from 562 million eggs in 2020 to 790 million eggs in 2024, which indicates the modernisation of poultry farming. However, wool production remains virtually unchanged, which may indicate limited changes in this industry or an insufficient level of its development (Table 2).

Table 2. Crop production in Kyrgyzstan for 2020-2024, thousand tonnes

Year	2020	2021	2022	2023	2024
Grain	1,856	1,329.1	1,867.3	1,623.8	2,156.7
Wheat	629.1	362.7	592.5	440.4	701.2
Barley	510.2	274	539.6	382.1	646.4
Corn	714.1	691.1	732.6	799.9	804.5
Rice	44.5	46.3	44.2	46.8	50.4
Legumes	107.2	85.5	80.7	72.3	82.6
including beans	103.6	82.6	78.3	69.9	-
Sugar beets	448.8	365.6	468.1	621	842.2
Raw cotton	72.8	66.9	76.5	63.5	48
Tobacco	1	1.1	1.2	1.5	0.9
Oilseed crops	23.9	17.8	19.7	15.3	18.6
Potatoes	1,327.2	1,289.1	1,275	1,286.8	1,190.3
Vegetables	1,131.2	1,114.1	1,163.6	1,216.6	1,214.1
Food melons	261.5	224.9	226.1	235.6	280.9
Fruits and berries	278	266.4	275.5	278.9	350.7
Grapes	9.3	7.4	7.3	5.1	6.9

Source: based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

Table 2 shows the heterogeneous dynamics in crop production in Kyrgyzstan for 2020-2024. Grain crops, including wheat and barley, showed significant fluctuations with a recovery by 2024, while corn and rice showed steady growth. Sugar beet production has almost doubled, indicating its priority, while legumes and cotton have declined, probably due to low profitability. Potatoes, vegetables, and melons remain relatively stable, with a slight decline in potatoes in 2024. The growth of fruit and berry production is noteworthy, which indicates the development of horticulture, while viticulture continues to decline. The results underscore the necessity to enhance the sustainability of grain production and bolster industrial crops for the sustained advancement of the agro-industrial complex (Fig. 2). The steady growth in the volume of food, beverages, and tobacco

production in Kyrgyzstan in 2020-2024 is demonstrated, which indicates the development of the processing industry and its growing contribution to the country's economy. This growth may be due to several factors: an increase in domestic demand for processed products, improved technology, and the expansion of processing facilities. An increase in exports of finished products could also contribute to the growth of indicators, especially in the segments of environmentally friendly products and traditional goods. Food security includes four key components: the availability of food, its economic accessibility, the stability of supply, and the quality of nutrition. In the context of Kyrgyzstan, each of these components has its own characteristics and challenges. The availability of food is contingent upon the quantity of agricultural output and the extent of food imports (Fig. 3).



Figure 2. Volume of production of food products (including beverages) and tobacco products in Kyrgyzstan for 2020-2024, million KGS

Source: based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)



Figure 3. Volume of imports and exports of agricultural goods in Kyrgyzstan for 2020-2024, million USD

Source: based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

The volume of agricultural imports is steadily increasing, which may indicate a growing dependence on external supplies, especially in conditions of limited

domestic production and the influence of global economic factors. In 2024, the volume of imports amounted to USD 359.3 million, which is significantly higher than in 2020 (USD 159.9 million). Exports of agricultural products are generally showing positive dynamics, but the increase in exports does not compensate for the increase in imports, which indicates a continuing imbalance in trade in agricultural goods.

Dependence on imports in key categories such as sugar, vegetable oil, and certain types of grain makes Kyrgyzstan's food system vulnerable to fluctuations in global prices and possible supply disruptions. Categories of commodities, including meat and edible offal, milk and dairy products, wheat, and vegetable oil, exhibit substantial import growth, signifying ongoing reliance on external sources to satisfy domestic demand. The import volume of meat and food by-products rose from USD 33.9 million in 2020 to USD 69.2 million in 2024. This reflects the need for import substitution and expansion of domestic production in order to reduce dependence on external supplies. Particular attention should be paid to the increase in wheat imports, which is of key importance for Kyrgyzstan's food security, as the country is heavily dependent on external grain supplies. Wheat imports increased from USD 35.1 million in 2020 to USD 81.4 million in 2024, underscoring the need to increase agricultural efficiency and improve grain production in the country (National Statistical Committee of the Kyrgyz Republic, n.d.).

The economic availability of food is related to the income level of the population, food prices, and the possibilities of their purchase. In Kyrgyzstan, where a significant part of the population has relatively low incomes, even a small increase in the prices of basic products can dramatically worsen access to food. Currency fluctuations, inflation, and dependence on imports exacerbate this problem. Government subsidy programmes and social assistance help the most vulnerable segments of the population, but their scope remains limited (Table 4).

Table 4. Purchasing power of monetary income of basic foodstuffs in Kyrgyzstan for 2020-2024 kg per month

Year	2020	2021	2022	2023	2024
Beef	15.7	14.7	16.1	18.5	19.1
Milk (litres)	184.9	194	172.9	193.6	192.1
Eggs (units)	713	665.4	789.2	840.6	860.5
Frozen fish	25.7	26.9	26.6	27.3	27.9
Granulated sugar	121.3	105.3	89.5	109.9	105.4
Vegetable oil	59.2	44.2	48.6	68.7	75.5
Animal butter	16.6	18.3	16.7	18	19.6
Potatoes	241.4	210.4	244.6	300	284.1
Wheat bread	119.2	130.1	131.4	136.4	140.5

Source: based on data from the National Statistical Committee of the Kyrgyz Republic (n.d.)

Overall, there is a positive trend in most items, which may indicate an improvement in food availability for the population, despite price fluctuations and economic challenges. For example, the purchasing power for beef increased from 15.7 kg in 2020 to 19.1 kg in 2024, and for eggs – from 713 to 860.5 units per month. This indicates a slight increase in household incomes or a stabilisation of prices for certain products. The stability of food supply depends on the stability of supply chains,

climatic conditions, and geopolitical factors. Kyrgyzstan, as a mountainous country, is subject to climate risks, including droughts, spring frosts, and reduced water resources, which affect agricultural yields. Disruptions in logistics chains, especially in winter, can lead to temporary shortages of some products in certain regions. In addition, high dependence on imports makes the food system sensitive to changes in the trade policies of supplier countries.

The quality and safety of food are dictated by dietary diversity, nutritional availability, and sanitary norms. In Kyrgyzstan, despite the accessibility of traditional natural goods, there exists a nutritional imbalance: the intake of meat and dairy products is elevated, whereas the consumption of vegetables, fruits, and fish is inadequate. The lack of knowledge about healthy eating, especially in rural areas, is also a problem. In addition, food safety control needs to be further improved, as cases of food infections and substandard products are still found on the market.

Climate change has a significant impact on agriculture in Kyrgyzstan, changing agro-climatic conditions and increasing risks to the production of major crops and livestock. Key challenges include rising temperatures, decreasing precipitation, and an increase in the frequency of extreme weather events such as droughts, floods, and sudden temperature fluctuations. Climate change may negatively affect the yield of wheat, the main food product in Kyrgyzstan. Droughts and high temperatures can reduce yields, because plants do not receive enough moisture in conditions of water scarcity. In 2021, Kyrgyzstan experienced significant droughts, which affected yields, reducing domestic production and increasing dependence on imports. Wheat harvest decreased by 42%, barley – by 49%, leguminous crops – by 18%. Grain yields dropped from 31.5 to 21.1 hundredweight per hectare (Ulukbek, 2021).

Rising temperatures and unstable weather conditions affect the health and productivity of livestock. An elevation in air temperature diminishes dairy productivity in cows and results in a rise in animal illnesses. Under elevated temperatures, cattle experience heightened stress, leading to diminished output and increased treatment costs. This is especially noticeable for small farms, where the cost of veterinary services can significantly affect the economic sustainability of farms. In addition, droughts and shortages of forage resources can increase the cost of feed, making farming particularly difficult for small farmers. The lack of water resources and high-quality feed directly affects the health of animals and their productivity.

The integration of modern technology into Kyrgyzstan's agro-industrial complex is crucial for enhancing agricultural efficiency and securing the nation's food supply. Precision farming, satellite monitoring, and automated irrigation systems occupy a special place among such technologies. Precision farming employs advanced information technologies to enhance the management of agricultural processes. In Kyrgyzstan, with the development of 5G networks, farmers can more accurately monitor the condition of fields and respond in a timely manner to crop needs for irrigation, fertilisers, or pest control. For example, the irrigation system can be controlled via a smartphone, which greatly simplifies the process and increases its efficiency (5G will make..., 2022).

Satellite monitoring and the use of drones allow obtaining detailed data on the condition of crops and land plots. The Ministry of Agriculture of Kyrgyzstan has already started implementing these technologies to determine acreage and forecast yields. Using satellite imagery and drones, specialists can identify problems at an early stage, such as the lack of moisture or plant diseases, and take appropriate measures (Akhmatova, 2023). Automated irrigation systems allow using water resources efficiently,

which is especially important for Kyrgyzstan with its mountainous terrain and limited water resources. The integration of such systems with soil moisture sensors and weather stations ensures optimal irrigation conditions, reducing water costs and increasing yields.

One of the main ones is the weak infrastructure: insufficient high-speed Internet coverage in rural areas limits the possibilities of using precision farming and remote monitoring technologies. Farmers, especially in remote regions, do not have access to up-to-date data processing systems, which reduces their work efficiency. Moreover, limited funding remains a major obstacle. The high cost of equipment and technologies makes it difficult for most farmers to purchase them, especially small farms, which make up a significant part of the Kyrgyz agro-industrial complex. Many agricultural enterprises cannot afford investments in innovative solutions without government support or preferential loan programmes.

An additional challenge is the lack of qualified personnel. The lack of specialists capable of working with the latest equipment and analysing the data obtained slows down the process of digitalisation of agriculture. Many farmers do not have the necessary knowledge to work with new technologies, which requires large-scale educational programmes and advanced training for farmers. Nevertheless, despite these challenges, there are successful examples of innovative solutions in the world that can become a reference point for Kyrgyzstan.

The Netherlands exemplifies the successful integration of digital technologies in agriculture. Automated greenhouses using humidity and temperature sensors, artificial lighting systems, and robotic harvesting are widely used in one of the leading countries for the development of agricultural technologies. Companies such as LettUs Grow are developing aeroponic farms where plants are grown without soil, which significantly reduces water and fertiliser consumption. In Israel, a nation characterised by a dry climate, drip irrigation methods have diminished water use by 50% and augmented output by 30%. Netafim has designed precision irrigation systems that calibrate water delivery based on the requirements of the plants (Schnarch, 2024). These solutions can also be adapted for Kyrgyzstan, where the problem of water supply remains urgent.

Satellite monitoring technologies for agriculture are actively developing in the USA. The Planet Labs start-up provides farmers with high-resolution satellite images that allow them to monitor the condition of fields in real time and respond in a timely manner to changes in plants. The introduction of such technologies in Kyrgyzstan could help in the early detection of plant diseases and optimise the use of fertilisers. Another promising example is robotic farms in Japan, which use automatic systems for plant care, harvesting and product sorting. Spread has built the world's first fully automated lettuce farm, where robots perform all key processes from planting to packaging products. In Kyrgyzstan, such technologies could be applied in greenhouses, reducing labour costs and increasing production efficiency.

Government programmes focused on agricultural and processing industry development serve as cornerstones for Kyrgyzstan's economic advancement. The programmes align strategically with the United Nations'

Sustainable Development Goals (n.d.), creating a framework that addresses interconnected global challenges including poverty reduction, hunger elimination, climate adaptation, and sustainable resource management. The implementation of these development strategies reflects Kyrgyzstan's commitment to achieving meaningful progress across multiple sectors simultaneously. Agricultural modernisation becomes a vehicle for broader social and economic transformation, connecting rural communities to national development objectives while maintaining environmental sustainability principles.

Sustainable Development Goal 2, which targets hunger elimination, holds particular significance for Kyrgyzstan's development trajectory. The country's agricultural sector must evolve to guarantee consistent access to safe, nutritious food for all citizens while building resilience against various challenges. Agricultural productivity enhancement emerges as a critical pathway toward food security objectives. The integration of modern farming techniques, combined with sustainable land and water management approaches, creates opportunities for substantial yield improvements. Given Kyrgyzstan's heavy reliance on natural conditions for agricultural success, efficient resource utilisation becomes essential for long-term viability. Water resource management stands as a particularly crucial element in this development equation. The introduction of advanced irrigation systems, including precision drip irrigation technology, offers significant potential for both increasing crop yields and reducing vulnerability to drought conditions.

Sustainable Development Goal 12 addresses the critical need for sustainable consumption and production patterns through the adoption of environmentally friendly technologies and the reduction of agricultural waste. Kyrgyzstan can advance this goal by implementing organic farming methods and agroforestry systems while minimising product losses throughout the entire agricultural value chain, from initial cultivation through processing and storage phases. The country's state agricultural cooperation programme should prioritise environmental impact reduction to ensure long-term agricultural sustainability and preserve natural resources for future generations.

Sustainable Development Goal 13's focus on climate action holds particular significance for Kyrgyzstan, as the nation faces considerable vulnerability to climate variability and extreme weather events. The country regularly experiences droughts, floods, and unpredictable weather patterns that directly threaten crop yields and food security. Agricultural adaptation strategies must include the development and deployment of climate-resistant crop varieties, implementation of efficient water conservation technologies, and strengthening of agricultural systems to withstand extreme weather conditions. Simultaneously, Kyrgyzstan must pursue greenhouse gas emission reduction strategies within its agricultural sector by adopting more efficient land cultivation practices and decreasing reliance on chemical fertilizers.

The National Development Programme of the Kyrgyz Republic until 2026 (2021) is a pivotal strategic document that delineates the primary domains of the nation's socio-economic advancement, emphasising the agro-industrial complex as the most critical sector of the economy.

The programme aims to address many tasks that will enhance the sustainability and competitiveness of the agricultural industry while ensuring food security for the nation's population. One of the main objectives of the National Development Programme of the Kyrgyz Republic until 2026 is to reduce dependence on imports of key food products such as wheat and sugar. Wheat production is expected to increase by 30% by 2026 and reduce dependence on imports from 30% to 15%. This implies not only an increase in domestic production, but also the introduction of innovative approaches to improve agricultural products, which will reduce the risks associated with external economic and political instability. The programme provides for the modernisation of the agro-industrial complex, including the introduction of up-to-date technologies, digitalisation of processes, the development of precision agriculture, and the improvement of irrigation infrastructure.

An important element of the National Development Programme of the Kyrgyz Republic until 2026 is the support of farms and agricultural cooperatives. The programme aims to create effective mechanisms that will help small and medium-sized enterprises use government assistance measures such as subsidies for machinery and fertilisers, preferential loans, and training and advanced training programmes. The National Development Programme of the Kyrgyz Republic until 2026 emphasises the sustainable management of natural resources. This encompasses soil and pasture restoration, judicious water resource utilisation, and effective irrigation, which is particularly crucial for Kyrgyzstan, since agriculture is contingent upon climatic circumstances. The programme provides for measures to adapt the agro-industrial complex to changing climatic conditions, such as increasing resilience to droughts and other extreme weather events.

The Programme for the Development of Agricultural Cooperation in the Kyrgyz Republic for 2023-2027 (Resolution of the Cabinet of Ministers of the Kyrgyz Republic No. 41, 2023) is aimed at strengthening the cooperative movement in the country's agricultural sector. The programme's goals include the creation and development of agricultural cooperatives to bring together small and medium-sized farms, which will increase production efficiency and improve access to resources. The initiative seeks to implement cutting-edge technology and agricultural techniques via cooperatives to enhance product volume and quality, while improving cooperatives' access to local and international markets, hence augmenting product competitiveness.

The main activities of the programme are the creation of agricultural cooperatives, it is planned to create 25 cooperatives specialising in various areas of agriculture, including crop production, animal husbandry, and processing. The programme encompasses the organisation of training sessions and seminars for cooperative members focused on management, marketing, finance, and the application of cutting-edge agricultural technologies. A crucial component of the programme is the allocation of preferential loans and subsidies for the acquisition of agricultural machinery, seeds, fertilizers, and other essential supplies. The programme also aims to build and modernise warehouses, refrigerators, processing plants, and logistics centres to improve product storage and transportation.

The anticipated outcomes of the programme encompass heightened production resulting from the collaborative endeavors of farmers and the implementation of cutting-edge technologies, augmented farmers' incomes attributable to improved conditions for cooperative members, enhanced food security through increased agricultural efficiency, and the provision of high-quality, affordable food to the populace. The programme seeks to diminish reliance on agricultural imports and enhance the nation's self-sufficiency. In 2024, 59 new agricultural cooperatives were established as part of the programme implementation, cultivating 4,500 hectares of land and having 413 members (Kamchybekova-Kabar, 2025).

Increasing agricultural productivity through cooperatives helps to increase food production, improve product quality, and ensure a more stable supply to local markets. This reduces dependence on imports and contributes to an increase in domestic production, which makes the country more resilient to external economic and climatic shocks. International cooperation and the experience of other countries play a significant role in the development in Kyrgyzstan. One such example is the Food and Agriculture Organization (n.d.) project in Central Asia. The project aims to increase the sustainability of agriculture and improve its productivity. In particular, water-saving technologies such as drip irrigation and the use of more efficient agricultural practices are being introduced. The project also includes training farmers in new farming methods, which significantly improves their knowledge and production skills, improving work efficiency and reducing costs. This cooperation improves the general conditions for farmers, stimulates production growth, and contributes to the development of the country.

The introduction of the latest irrigation and water management technologies is also an important aspect for efficient agriculture. Israel's experience in water conservation and precision farming is a global benchmark. Drip irrigation technologies introduced in Israel have significantly increased yields while reducing water consumption (Strawberries in the desert..., 2023). This experience can be adapted for Kyrgyzstan, especially in regions where water resources are limited, such as the southern and eastern regions. The Israeli approach allows significantly increasing the efficiency of agriculture, reducing water supply costs, and improving the general conditions for farming in conditions of limited natural resources.

Uzbekistan, as Kyrgyzstan's closest neighbour, also has valuable experience in agricultural development. Uzbekistan has implemented the "Uzbekistan – 2030" strategy (The Government Portal of the Republic of Uzbekistan, 2024), which includes a range of agricultural improvement programmes such as the development of agricultural cooperatives, improved irrigation, and the introduction of resistant plant varieties. These measures have significantly increased agricultural productivity and strengthened the country's food security. Kyrgyzstan can derive insights from Uzbekistan's experience, particularly regarding the advancement of agricultural cooperatives, water management, and the implementation of novel crop types, which will enhance productivity and bolster the sustainability of the agricultural sector.

The economic instability and limited resources, a combination of strategic government planning and active involvement of private investment is necessary. The advancement of precision agriculture, implementation of soil monitoring systems, utilisation of moisture control sensors, and deployment of automated irrigation systems can markedly enhance the efficiency of land and water resources. This is particularly evident in the mountainous areas of the country, where soil erosion and water scarcity restrict agricultural options. To support this initiative, it is recommended to create specialised agricultural technology centres that will train farmers and provide access to up-to-date equipment. Another area is the diversification of agricultural production. To reduce dependence on imports of cereals, oilseeds, and other strategically important crops, it is necessary to develop their domestic production. This can be achieved by increasing the acreage, subsidising seed material and introducing more productive varieties. In addition, it is necessary to stimulate the cultivation of crops with high added value, such as berries, nuts, and medicinal plants that have export potential.

Kyrgyzstan's agricultural sector faces significant losses from inadequate storage and processing infrastructure, requiring urgent development of regional logistics centres equipped with modern storage and processing capabilities. These facilities would substantially reduce product waste while enhancing the competitiveness of local goods in both domestic and international markets. Strengthening food security also demands comprehensive water management reform through advanced irrigation technologies. Implementing drip irrigation systems and automated water distribution controls would dramatically reduce water waste while boosting agricultural yields. This dual approach of improving infrastructure and modernising water systems creates a foundation for sustainable agricultural growth that addresses both immediate food security concerns and long-term economic development goals.

Improving farmers' access to financial resources is essential. The government should develop concessional lending and insurance programmes, which will allow farms to cope with the risks associated with weather disasters and market instability. It is also important to promote the creation of agricultural cooperatives that can pool farmers' resources to increase their competitiveness and strengthen their bargaining position in the market. Implementing educational initiatives on ecological farming, minimising the application of chemical fertilizers and pesticides, and advocating for organic agriculture would contribute to the conservation of natural resources while enhancing the appeal of Kyrgyz products in environmentally conscious international markets. Moreover, it is essential to enhance collaboration with international organisations, such as the Food and Agriculture Organization and the World Bank, to secure financing and use optimal methods. The potential for enhancing food security in Kyrgyzstan is linked to the comprehensive growth of the agro-industrial sector, infrastructure modernisation, the adoption of innovative technologies, and the judicious utilisation of natural resources. These initiatives, alongside governmental assistance and global collaboration, will enhance food security, bolster the competitiveness of domestic agriculture, and guarantee the sustainable advancement of the nation.

► Discussion

Food security research in the Kyrgyz Republic reveals that the country's agricultural sustainability depends on a complex interplay of internal and external factors affecting the agro-industrial sector. The nation struggles with significant reliance on imported food despite having considerable agricultural potential. Production instability plagues key strategic crops including wheat, sugar, and vegetable oil, with grain and sugar beet yields experiencing substantial fluctuations that directly impact food accessibility for citizens. The findings emphasise that addressing food security requires a comprehensive approach that considers both the country's internal agricultural capacity and external market dependencies.

The disconnect between Kyrgyzstan's farming potential and its actual food production stability highlights the need for systematic improvements in agricultural productivity and supply chain resilience (Shebanina *et al.*, 2024). Excessive reliance on external sources engenders susceptibility to global economic and climatic crises, including price volatility in international markets and the repercussions of climate change, which may result in increased prices and scarcity of products. E. Workie *et al.* (2020) also investigated the development of the processing industry in agriculture could reduce the country's dependence on external food supplies. U. Sekaran *et al.* (2021), in turn, argued that in order to ensure food security, it is necessary to develop domestic production of products, rather than relying on imports.

Low incomes of the population, poverty, and uneven distribution of wealth become barriers to providing adequate nutrition, even in conditions of sufficient production (Chechitko *et al.*, 2024). The problem is that, despite the availability of agricultural potential, most rural residents are engaged in agriculture for self-sufficiency, which limits their participation in the market economy and makes it difficult to expand processing capacities. A. Cattaneo *et al.* (2022) pointed out that a large number of rural households depend on self-sufficiency, which makes them vulnerable to economic crises. Y. Huang & Y. Zhang (2020), in turn, noted that poverty and income inequality hinder full access to high-quality food. Current results have shown a similar conclusion that the problem of poverty and inequality is a key factor that limits food availability, but it is necessary to focus on external factors such as dependence on imports and changes in global prices.

Kyrgyzstan, characterised by its high-altitude climate, is encountering issues associated with droughts, floods, and land degradation. These variables adversely affect yields, particularly in regions where agriculture constitutes the primary source of income. D. Xiao *et al.* (2020) noted that a reduction in precipitation in the summer months leads to significant crop losses. A. Pareek *et al.* (2020) also concluded that global climate change, especially rising temperatures and changing precipitation patterns, significantly reduces areas suitable for agriculture and reduces yields. The current results confirm this trend, but unlike the researchers' study, specific adaptation measures have been proposed, including the introduction of drought-resistant crops and drip irrigation systems. Technological solutions, such as the introduction of precision farming

and improved water management, could reduce agriculture's vulnerability to climate risks etc (Samoichuk *et al.*, 2016; Kiurchev *et al.*, 2020).

The development of the agro-industrial complex of Kyrgyzstan involves not only increasing production volumes, but also strengthening processing capacities. Processing agricultural products not only improves food availability, but also creates additional jobs, which contributes to economic growth (Ismayilov *et al.*, 2023). The development of agricultural processing in the context of Kyrgyzstan requires comprehensive government support, including subsidies, easier access to credit resources, and infrastructure development. M.W. Scown *et al.* (2020) concluded that agricultural subsidies may be distributed inefficiently, which leads to limited access of small farmers to financial resources. The current study also noted insufficient support for farmers, but the main focus is on the need to develop processing facilities, which was not considered by the researchers.

D. Laborde *et al.* (2021) conducted a study on agricultural subsidies and their impact on food security. They discovered that, despite the presence of governmental assistance, ineffective allocation of resources and insufficient coordination among different government entities resulted in a frail development of the agro-industrial sector and an acute decline in food security. The present study highlighted the inefficacy of governmental support and coordination, while underscoring the necessity of a holistic public policy that encompasses all facets of agricultural and food security.

The research has shown the need to diversify agriculture, which will help reduce dependence on traditional crops and increase export potential. The development of the culture of berries, nuts, and other export-oriented goods can become an important area in ensuring the sustainability of the food system. A key aspect in this context is to improve the storage and transportation infrastructure, which will help to minimise product losses and increase its competitiveness in international markets. An important element in ensuring food security is the involvement of innovative technologies such as biotechnologies, monitoring systems, and digitalisation of agriculture (Bulgakov *et al.*, 2020). The introduction of such technologies will increase resilience to climate change and improve agricultural production management, which, in turn, will strengthen the country's food security. S.A. Ashraf *et al.* (2021) argued that the introduction of new technologies such as precision farming systems and the use of genetically modified crops could significantly increase agricultural productivity and reduce its vulnerability to climate risks. The current study focused on a broader approach, including sustainable water management and improved agricultural technology, while the researchers focused more on specific technologies such as genetic modification.

► Conclusions

The key achievements and problems of the agro-industrial complex of the Kyrgyz Republic were analysed. The study indicated that there has been a favourable trend in animal production, crop production, and processing industries in recent years. For example, meat production increased

from 401,000 tonnes in 2020 to 460,000 tonnes in 2024, reflecting advances in the development of meat farming. Similar trends can be seen in milk production, which increased from 1.668 million tonnes to 1.824 million tonnes over the same period, indicating improved conditions for keeping and feeding livestock. The output of food, drinks, and tobacco products rose from KGS 35 billion in 2020 to KGS 87 billion in 2024, indicating advancements in processing technologies and capacity enhancement.

Significant progress has also been noted in crop production, although the dynamics there were more heterogeneous. Sugar beet production has almost doubled, demonstrating the priority development of this crop, while grain production, including wheat and barley, was subject to significant fluctuations, but recovered by 2024. Stability was noted in the production of potatoes, vegetables, and melons, although their volumes have decreased slightly by 2024. In 2024, the volume of imports amounted to USD 359.3 million, which is significantly higher than in 2020 (USD 159.9 million). This may indicate a growing dependence on external supplies. The purchasing power of monetary incomes of basic foodstuffs showed a positive trend. For example, the purchasing power for beef increased from 15.7 kg in 2020 to 19.1 kg in 2024, and for eggs – from 713 to 860.5 units per month. This indicates a slight increase in household incomes or a stabilisation of prices for certain products.

Public policy and international cooperation play crucial roles in ensuring food security, as demonstrated by key initiatives in the Kyrgyz Republic. The National

Development Programme running until 2026 focuses on agricultural modernisation, sustainable farming practices, and reducing import dependency. This domestic effort aligns with broader international frameworks like the 2030 Sustainable Development Goals. The Agricultural Cooperation Development Programme for 2023-2027 represents another significant policy intervention designed to enhance farm efficiency through cooperative formation, improved market access, and advanced agricultural technology adoption. These coordinated efforts illustrate how national and international strategies can work together to strengthen food systems. However, the research faced constraints due to limited data availability from the agro-industrial sector and its international market connections. Future studies should examine climate change impacts on agriculture more thoroughly and develop comprehensive adaptation models for managing external economic and environmental challenges. This deeper analysis would provide better insights into building resilient agricultural systems capable of withstanding various global pressures.

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Проблеми та перспективи продовольчої безпеки в агропромисловому комплексі Киргизстану: економічний аналіз і рекомендації

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► **Анотація.** Дослідження було присвячено аналізу стану агропромислового комплексу Киргизької Республіки для розроблення заходів для його модернізації в контексті забезпечення продовольчої безпеки. У роботі було використано аналітичний підхід, що включав системний аналіз статистичних даних по сільському господарству, тваринництву та харчовій промисловості. Основну увагу приділено вивченню динаміки сільськогосподарського виробництва, включно зі зростанням обсягів тваринницької та рослинницької продукції, а також аналізу поточних тенденцій у переробці та виробництві продуктів харчування. Під час дослідження виявлено основні виклики, що впливають на продовольчу безпеку: зміна клімату, цінова нестабільність на світових ринках, залежність від імпорту та недостатня інфраструктура. Наголошено на проблемах, пов'язаних із переробкою та зберіганням продукції, а також із доступом фермерів до фінансування. Відзначено позитивні тенденції зростання обсягів виробництва продовольчих товарів, що підкреслює важливість розвитку національного агропромислового комплексу. На основі аналізу запропоновано рекомендації, що включають диверсифікацію сільськогосподарського виробництва, впровадження інноваційних технологій, підвищення ефективності використання водних і земельних ресурсів, а також розвиток сільськогосподарських кооперативів. Особливу увагу приділено створенню регіональних логістичних центрів, поліпшенню інфраструктури зберігання та переробки, а також посиленню державної підтримки. Було наголошено на необхідності координації з міжнародними організаціями, такими як Організація Об'єднаних Націй та Світовий банк, для реалізації стратегій сталого розвитку, включно з Цілями сталого розвитку. Дослідження надало всебічний аналіз поточної ситуації та практичні рекомендації, спрямовані на зміцнення продовольчої безпеки Киргизстану в умовах глобальних викликів. Отримані результати можуть бути використані державними органами, агропідприємствами та фермерами для розроблення стратегій розвитку сільського господарства, підвищення його стійкості та забезпечення продовольчої незалежності країни

► **Ключові слова:** сільське господарство; сталий розвиток; управління ресурсами; технологічна модернізація; державна політика



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Economic analysis of marketing strategies to improve the competitiveness of food industry enterprises in the agro-industrial complex

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► **Abstract.** The purpose of this study was to analyse the marketing strategies of food industry enterprises in the Mykolaiv region to increase their competitiveness. The study investigated the economic state of the region's food industry, analysed current marketing practices, and assessed the competitive environment. The study employed a wide range of methods, including statistical analysis, SWOT analysis, benchmarking, and economic and mathematical modelling to forecast product demand. Based on official statistics, practical examples of local enterprises (Olkom, Chumak) and global marketing practices (Nestlé, Unilever, Coca-Cola, Danone), the strengths and weaknesses of enterprises in the region were identified, as well as opportunities for development. The study found that the key advantages include access to high-quality raw materials, regional brand recognition, and the potential for using digital technologies. The key challenges include limited marketing budgets, dependence on seasonality, and high competition from large national and international producers. Recommendations were developed for adapting marketing strategies to the specific characteristics of the region, including the use of local advantages (geographical location, access to resources), the introduction of modern marketing tools, improved interaction between farmers and food industry enterprises, and the creation of clusters to increase efficiency. It was proposed to use international practices to design sustainable development programmes, create unique local products, and introduce innovations in distribution and logistics. The findings of the study can be used by food industry enterprises in the Mykolaiv region to optimise marketing strategies, increase competitiveness, and strengthen their positions in internal and external markets

► **Keywords:** business; agriculture; secondary sector; management methods; sales profitability

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► Introduction

The relevance of the study lies in the growing competition in internal and external markets. In the current conditions of globalisation and Ukraine's integration into international trade systems, food industry enterprises are faced with the need to respond quickly to changes in demand, improve product quality, and adapt to international standards. At the same time, growing consumer interest in environmentally friendly and organic products creates new opportunities for the development of the industry. To ensure sustainable competitive advantages, enterprises must develop effective marketing strategies based on modern market analysis methods, innovative approaches to distribution, logistics, and product promotion. Particular focus should be made on the use of digital technologies, such as Big Data, CRM systems, and analytical platforms, to gain a deeper understanding of consumer preferences and personalise offers. Improving the competitiveness of food industry enterprises also contributes to the development of the agro-industrial complex as a whole, strengthening Ukraine's export potential and integration into the global market. Analysis of the economic aspects of marketing strategies allows identifying the most effective approaches, optimising costs, and ensuring sustainable development of the industry. Therefore, research on this topic is valuable both from a scientific and practical standpoint for enterprises in the industry.

In the modern globalised world, the competitiveness of food industry enterprises is becoming an essential factor in ensuring the economic stability of regions and countries. The Mykolaiv region, which has strong agro-industrial potential, faces the challenges of integration into global markets and adaptation to modern economic conditions. The region's food industry is represented by both large export-oriented producers and small and medium-sized enterprises focused on local markets. At the same time, the effectiveness of marketing strategies continues to be a significant factor determining the ability of enterprises to compete in the context of increasing globalisation (Saeed *et al.*, 2024). Analysing the issue of food security, I. Petrunenko *et al.* (2021) emphasised the need for a comprehensive approach to forming competitive advantages for food industry enterprises, particularly through strategic planning and the implementation of effective marketing solutions. The researchers emphasised that it is marketing activities focused on the principles of sustainable development that can become a tool for improving the efficiency of enterprises in the face of global competition. D. Saveliy *et al.* (2024) investigated the possibility of extracting useful components from sunflower oil hydration waste, which reduces the environmental impact of production and increases the economic efficiency of enterprises.

A. Belinska *et al.* (2024) proposed chemical methods for inactivating lipoxygenases in flax raw materials, which improves product quality and expands its use in functional foods. Research on the competitiveness strategies of agro-industrial enterprises conducted by A. Kobets *et al.* (2021) emphasised the significance of implementing cluster initiatives that promote more effective cooperation between producers, processors, and distributors. In the field of strategic marketing for small and medium-sized enterprises, H. Sukier *et al.* (2024) analysed the adaptation of

local strategies to global markets using the example of the Colombian baking industry, demonstrating how the integration of local approaches with modern technologies can help attract customers and increase profitability. B. Wood *et al.* (2021) investigated the market strategies of large processed food manufacturers that use mergers, product range expansion, and aggressive advertising to consolidate market power. This study is valuable for understanding the competition faced by small and medium-sized enterprises. S. Khan *et al.* (2021) explored the effects of technological innovation and the circular economy on business strategies in the context of the COVID-19 pandemic, emphasising the need to adapt to emerging challenges.

A review of circular models in agri-food systems by M. Hamam *et al.* (2021) provided a basis for developing strategies to minimise waste and use resources efficiently. A. Satpathy *et al.* (2024) stressed the significance of implementing sustainable practices in the food industry that ensure compliance with environmental requirements and changing consumer preferences. M. Baskoro *et al.* (2024) investigated the effectiveness of marketing communications, showing how environmental values can be integrated into business strategies to increase customer loyalty. F. Badia *et al.* (2024) explored the possibilities of integrating agritourism into the food industry, proposing new models for creating added value.

Despite considerable interest in marketing strategies, regional specifics, specifically the adaptation of international practices to the conditions of the Mykolaiv region, are still understudied. Seasonality, limited financial resources, and competitive pressure require a comprehensive approach to analysis and innovation. The purpose of the present study was to examine the marketing strategies of food industry enterprises in the Mykolaiv region and assess their effectiveness. The objectives of the study were to analyse the marketing strategies of food industry enterprises in the Mykolaiv region, evaluate the effectiveness of the marketing approaches used, and develop recommendations for improving the competitiveness of enterprises in the region.

► Materials and methods

This study employed an interdisciplinary approach to analyse the marketing strategies of food companies in the Mykolaiv region. The study was based on quantitative and qualitative methods, which provide a comprehensive understanding of the issues. The primary sources of data were official statistical reports from the Main Department of Statistics in Mykolaiv region (n.d.), which contained information on production volumes, exports, imports, and investment activity of enterprises in the period from 2020 to 2024. Specifically, data on the volume of exports of oil, juices, and grains, which form the basis of the region's agro-industrial potential, were considered. Furthermore, international databases such as the UN Comtrade Database (n.d.) were used to provide comparisons with the situation in other countries, particularly Germany, Poland, and Turkey, where the food industry has comparable characteristics and challenges.

To analyse the competitive environment and the effectiveness of marketing strategies, case studies of local companies such as Olkom (n.d.) and Chumak (n.d.) were used,

as well as global practices of Nestlé (n.d.), Unilever (n.d.), Coca-Cola (n.d.), and Danone (n.d.). This helped to examine approaches to adapting products to regional and international markets. The study employed SWOT analysis to identify the strengths and weaknesses of companies, as well as the opportunities and threats associated with marketing strategies. Methods of marketing strategy analysis were also analysed: return on investment (ROI), which allows assessing the relationship between marketing investments and the income received. Benchmarking was another effective tool that involved comparing one's marketing strategies with best practices in the industry. The use of economic and mathematical modelling helped to forecast demand for the products of enterprises in the region, considering variables such as seasonality, prices, and marketing costs. Tools such as Google Analytics and Meta Ads Manager were used to evaluate digital marketing campaigns. This helped to assess customer engagement through social media and the effectiveness of advertising campaigns.

► Results

Features of marketing strategies in local markets: International practices and theoretical approaches. In the context of the current digital transformation of marketing, particular attention should be paid to the implementation of digital tools to improve communication strategy, analyse consumer preferences, and personalise services. According to I. Banyeva *et al.* (2023), the use of innovative marketing technologies in branding ensures sustainable growth in brand awareness and loyalty, which can be effectively adapted in the agro-industrial sector to promote food industry products. One of the key areas for improving the competitiveness of food industry enterprises in modern conditions is the digitalisation of production and management processes. The use of digital technologies substantially reduces costs, optimises interaction with consumers, and improves the quality of management decisions, which directly influences the effectiveness of marketing strategies (Yekimov *et al.*, 2022).

Global practices demonstrate the significance of adapting marketing strategies to the specifics of local markets, including cultural, social characteristics, and economic and technological factors. International companies successfully integrate localisation into their strategies, enabling them to meet the needs of diverse consumer segments around the world. For instance, Nestlé (n.d.), using Big Data to forecast demand and personalise products, has achieved a 15%-20% increase in ROI. This demonstrates

the effectiveness of using technology to adapt products to local preferences, which increases profits and reduces marketing costs, improving overall profitability. In the case of India, the company adapted its products by changing flavour profiles to suit the region's culinary traditions. In Japan, Nestlé introduced a variety of KitKat flavours, such as matcha, which is popular in Japanese culture. This adaptation demonstrates the significance of factoring in the local cultural and gastronomic characteristics when developing marketing strategies. Notably, the introduction of AI tools has reduced the company's marketing research costs by 18%, demonstrating the effectiveness of using advanced technologies to improve the accuracy and speed of marketing decisions and reduce operating costs.

Unilever (n.d.) integrates sustainable development principles into its strategies, emphasising the environmental friendliness of its products. The company has reduced its environmental footprint by 30% through the application of a circular economy, which not only improved its environmental reputation but also enabled it to attract new customer categories, particularly among environmentally conscious consumers. Coca-Cola (n.d.) demonstrated the successful use of digital platforms to engage younger audiences, notably through campaigns on TikTok, which reached 1.5 million users in three months. This highlighted the value of using modern technologies to attract new consumer segments and increase engagement with the end consumer. In Mexico, Coca-Cola focuses on family values, while in China it focuses on traditional holidays such as Chinese New Year. Danone (n.d.), investing 20% of its marketing budget in social media, recorded a 25%-30% increase in online sales in 2023. This demonstrates the effectiveness of investing in digital channels to achieve marked sales growth in the online segment, which is part of a strategy to attract new customers and increase the loyalty of existing ones.

Analysing the effectiveness of marketing strategies in numerical terms allows clearly identifying the advantages and disadvantages of different approaches. Specifically, a comparison of profitability, ROI, and logistics costs for conventional, hybrid, digital, and environmentally-oriented strategies revealed substantial differences in their influence on the competitiveness of enterprises. For example, international companies demonstrate markedly better performance thanks to innovative solutions, while enterprises in the Mykolaiv region that rely on conventional methods fall behind due to technological and resource constraints (Table 1).

Table 1. Analysis of the effectiveness of marketing strategies in numerical terms

Strategy type	ROI, %	Profitability, %	Logistics costs, %	Examples
Conventional	8-10	10	20-25	Fairs, local advertising
Hybrid	12-15	15-18	15-18	"Chumak" (CRM + social media)
Digital	18-22	20-25	10-12	Nestlé (AI, Big Data)
Environmentally oriented	10-12	12-15	18-20	Danone (renewable resources)

Source: compiled by the authors

Digital strategies, particularly artificial intelligence and big data analytics, demonstrate the highest effectiveness due to their ability to accurately predict demand, automate processes, and optimise logistics (Palamarchuk &

Korkach, 2023). Conventional methods, such as fair participation and local advertising, have lower performance due to their high operating costs and limited scalability. Hybrid strategies, as exemplified by Chumak (n.d.),

combine conventional methods with digital tools such as CRM systems and targeted advertising, enabling increased efficiency even with limited resources. Environmentally focused strategies have long-term potential, as shown by Danone (n.d.), which increased customer loyalty using renewable resources. For the Mykolaiv region, this means the opportunity to enter European markets through organic certification. Therefore, the transition to hybrid or digital strategies is key for businesses in the region. Investments in modern technologies and environmental initiatives will not only bring enterprises closer to global leaders but also enable them to capitalise on competitive advantages such as access to high-quality raw materials.

The concept of strategic groups helps to understand how companies build their strategies within specific markets that are competitive for specific consumer segments. For example, in the organic products market, Danone (n.d.) and Nestlé (n.d.) form separate strategic groups, focusing on high-quality organic products for specific regions, such as Europe, where demand for such products is consistently high. Adapting these strategies to local markets is vital for companies seeking to increase their competitiveness. In regions with developed agro-industrial traditions, such as the Mykolaiv region, marketing strategies should focus on the local nature and environmental friendliness of products. Consideration of the specific characteristics of local resources, such as agricultural raw materials, as well as adapting to climatic and cultural characteristics, will contribute to the creation of competitive advantages in the market.

In the current conditions of global turbulence, it is also essential to ensure that agricultural production follows the principles of sustainable development. Research shows that the level of economic accessibility of food and the environmental stability of agricultural production are closely interrelated, which creates a basis for the development of adaptive marketing strategies aimed at environmentally conscious consumers (Poltorak *et al.*, 2023). O. Dovgal *et al.* (2022) emphasised that the implementation of circular economy principles contributes to the rationalisation of production and cost reduction, which is an essential element of sustainable development strategies. For food industry enterprises, this can mean improving resource efficiency, reducing waste, and improving their environmental image, all of which directly affect their competitiveness in internal and external markets.

Specifically, strategies that focus on the naturalness and environmental friendliness of products are significant for the Mykolaiv region. In regions where the consumption culture is oriented towards natural products, a strategy that emphasises the environmental friendliness and local origin of products can contribute to increased consumer loyalty and the competitiveness of food industry enterprises. Thus, local marketing strategies adapted to the specifics of the market and culture are key to success in a globalised world.

Marketing strategies of food industry enterprises in the Mykolaiv region. The marketing strategies of food industry enterprises in the Mykolaiv region are shaped by regional characteristics, among which the consumer habits of the local population and the raw material base play a key role. Producers such as Olkom (n.d.) and Chumak (n.d.)

focus on using local raw materials that meet the demand for natural and environmentally friendly products among the region's residents. This strategy is reinforced by the region's specialisation in the production of oil (28.8% of the total Ukrainian volume) and fruit and vegetable juices (40.3%), which are often produced to suit regional tastes (Main Department of Statistics in Mykolaiv region, n.d.).

S. Reshmidilova *et al.* (2024) showed that the use of artificial intelligence technologies in marketing strategies contributes to the personalisation of communication with customers, the automation of operations, and the formation of predictive models of consumer behaviour. This provides companies with competitive advantages and improves the effectiveness of interaction with consumers, which is a crucial factor in strengthening the competitiveness of food industry enterprises. A major factor determining the potential of an enterprise to implement innovative approaches in marketing activities is the level of human capital development (Shtal *et al.*, 2023). Investments in staff training, the creation of a motivating environment for professional growth and self-learning contribute to increased labour productivity and ensure the sustainable functioning of enterprises in a competitive market (Yekimov *et al.*, 2023). However, communication with consumers is mainly focused on conventional channels, such as local media or the organisation of tastings, which indicates the conservatism of the market and the priority of personal contact in conditions of limited budgets for digital marketing.

The Mykolaiv region is a prominent agro-industrial region of Ukraine, where the food industry plays a key role in the economy. According to 2024 data, exports of goods from the region in January-February amounted to USD 182 mn, which is 39.8% more than in the same period of the previous year. In the first quarter of 2024, exports reached USD 251.3 mn, which is 96.3% of the same indicator in 2023. The main export destinations were China, Germany, the United States, and Moldova, which indicates stable demand for the region's products on the international market. The food industry in the Mykolaiv region is represented by enterprises specialising in the production of meat, dairy products, flour, bread, oil, and juices. For instance, the region accounts for 28.8% of Ukraine's total oil production and 40.3% of fruit and vegetable juices. In 2024, 66.4% of food industry enterprises in the region were engaged in export activities, which exceeded the average for Ukraine (60.9%) (Main Department of Statistics in Mykolaiv region, n.d.).

A valuable factor influencing marketing decisions is the logistics infrastructure and access to transport hubs. Until 2022, the ports of the Mykolaiv region provided stable exports of grain and oilseeds, but due to the blockade of sea routes during the full-scale war, enterprises were forced to use alternative routes, particularly through EU countries (Romania, Poland), which substantially increased transportation costs and reduced-price competitiveness. This situation stimulated a shift towards land transport and the development of cooperation with countries that have stable demand for products, such as Germany and Moldova. To minimise risks, companies stepped up their efforts to build up strategic reserves of raw materials and finished products, which allows

them to maintain export operations even in conditions of unstable logistics (Main Department of Statistics in Mykolaiv region, n.d.).

The food industry in Mykolaiv region competes with a series of rival companies on both the internal and external markets. In the internal market, the primary competitors are large national brands such as Rud, MHP, Obolon, and Sandora. These companies have extensive financial and production resources, which allow them to conduct large-scale advertising campaigns, provide a wide range of products, and offer competitive prices. On the external market, competition is intensifying from international food producers such as Nestlé, Danone, and Unilever. These companies have many years of experience, developed distribution networks, and marketing strategies adapted to different regions of the world. For example, in the oil products segment, the key competitors for Mykolaiv producers are exporters from Argentina, Brazil, and Turkey, who have access to cheaper raw materials and actively use modern marketing approaches. A vital task for enterprises in the Mykolaiv region is to find their niche in the internal market by focusing on the environmental friendliness, local origin, and authenticity of their products. In external markets, they can strengthen their positions by improving the compliance of their products with international quality standards and using localised marketing strategies (UN Comtrade Database, n.d.).

Among the primary challenges for enterprises in the region is competition from imported products, especially in the processed goods segment, where foreign manufacturers offer lower prices. This forces local companies to focus on the quality and uniqueness of the regional origin of goods as key competitive advantages. Additional challenges are associated with high marketing campaign costs, limited access to international markets due to military risks, and the need to meet strict quality standards for exports. The instability of the raw material base, caused by seasonal fluctuations in crop yields (-24.7% in previous years) and economic uncertainty (business confidence indicator -8% in August 2024), creates further barriers to long-term planning (Main Department of Statistics in Mykolaiv region, n.d.).

In such conditions, it is critical to diversify sales markets, improve logistics chains, and integrate digital tools for product promotion, which will compensate for the structural weaknesses of the industry. Specifically, the use of modern digital platforms, such as CRM systems and targeted advertising on social networks, will enable companies to reduce marketing costs and increase conversion rates. Furthermore, investments in sustainable development and organic product certification will help to improve competitiveness in European markets. A SWOT analysis was conducted to assess existing marketing strategies, the results of which are presented in Table 2.

Table 2. SWOT analysis of food industry enterprises in Mykolaiv region

Category	Factors
Strengths	Availability of high-quality raw materials
	Regional brand recognition with an emphasis on locality and environmental friendliness
	Active use of digital platforms to promote farm products
	Product diversity (organic products, value-added products)
Weaknesses	Low scalability of marketing campaigns outside the region
	Insufficient use of modern analytical tools
	Limited marketing budgets in small and medium-sized enterprises
	Seasonal dependence of raw material supplies
Opportunities	Broader use of digital technologies such as Big Data and CRM systems
	Growing demand for organic products in Ukraine and beyond
	Improvement of export opportunities through international exhibitions and fairs
	Attraction of foreign investment to expand production
Threats	High competition from large national brands and imported products
	Economic instability and fluctuations in raw material prices
	Changes in regulatory requirements in the field of food safety and export
	Deterioration of climatic conditions affecting the availability of raw materials

Source: compiled by the authors

SWOT analysis showed that enterprises have significant advantages related to product quality and regional recognition. However, limited marketing budgets and insufficient use of modern technologies create problems for market expansion. At the same time, companies have significant opportunities to improve their marketing strategies, including the development of digital marketing, increasing export potential, and introducing innovative approaches to analytics. To overcome threats, it is vital to consider the instability of the economic situation and increased competition.

Development of recommendations to improve the competitiveness of enterprises in the region. Based on an

analysis of the marketing strategies of enterprises in the Mykolaiv region and a comparison with international experience, a series of strategic measures aimed at improving the competitiveness of local enterprises were proposed. The recommendations include adapting best international practices to regional conditions, improving the effectiveness of marketing strategies, developing technological infrastructure, and creating long-term partnerships to stimulate growth and expand exports.

The first step is to adapt international practices to regional conditions. One of the key areas of focus is the introduction of digital tools to optimise marketing budgets and improve customer engagement. Modern CRM

systems and data analytics platforms enable enterprises to automate customer marketing processes, increase demand forecasting accuracy, and make efficient use of limited resources. For instance, Danone's experience showed that integrating AI tools for social media analysis can increase online sales by 25%-30%. This is a crucial aspect for companies in the Mykolaiv region, where significant potential exists for developing online sales and using digital channels to attract customers.

Another major step is the development of cluster models that bring together farmers, processors, and distributors. This strategy reduces costs, increases production efficiency, and strengthens the region's competitive position. The experience of Unilever (n.d.) shows that the successful implementation of cluster models helps to reduce logistics costs by 15% and increase export potential. Polish experience also confirmed the effectiveness of such models: several agro-industrial clusters were created in the country, enabling small and medium-sized enterprises to reduce transport costs and increase export volumes (UN Comtrade Database, n.d.).

For the Mykolaiv region, which has a strong raw material base and a developed agro-industrial sector, the introduction of clusters could be a powerful tool for optimising production and entering new markets. It is vital to create infrastructure that will bring together enterprises from different sectors, which will reduce costs and ensure a stable supply of raw materials. To optimise their marketing strategies, enterprises in the Mykolaiv region must increase the share of digital channels in their overall marketing budget. The example of Nestlé (n.d.), which spends up to 12% of its budget on digital marketing, demonstrated how effective use of TikTok and Instagram can reach a young audience and attract new customers. For small and medium-sized enterprises, this means the opportunity to increase brand awareness by 25% and increase conversion by 12%-15%. Such changes will allow enterprises in the Mykolaiv region to improve their market position, increase advertising efficiency, and attract new consumers at minimal cost.

One of the key advantages of the Mykolaiv region is access to high-quality agricultural raw materials, including organic products, which can become the basis for the development of unique products with an emphasis on environmental friendliness. The 35% growth in demand for organic products in the European Union creates opportunities for expanding exports of certified products, as demonstrated by Olkom (n.d.), which increased oil prices by 20%-30% thanks to compliance with standards (FoodChain ID Certification, n.d.). The Mykolaiv region has promising potential for the production of organic and environmentally friendly products, which will allow its enterprises to gain access to more profitable markets and strengthen their reputation in the international arena.

The use of economic and mathematical models to forecast demand will enable enterprises in the Mykolaiv region to minimise the risks of overproduction and reduce storage costs. Nestlé's experience confirmed that the use of such tools can reduce storage costs by 25%, which is an essential aspect for food industry enterprises in the region. To implement these changes, it is necessary that local enterprises receive support through IT training programmes for managers, which will improve staff qualifications and

adapt modern technologies to local conditions. A strategic step for the Mykolaiv region is to establish partnerships with international brands. The example of Olkom (n.d.), which developed export hubs and partnerships, led to a considerable increase in export volumes. The Turkish practices showed that partnerships with international companies can increase exports by 40% in 5 years (UN Comtrade Database, n.d.). Such a strategy would be useful for enterprises in the Mykolaiv region, as it would enable them to access wider markets and improve their competitiveness at the global level.

The expected outcomes of implementing the recommendations are a 10%-15% reduction in operating costs, a 25%-30% increase in exports, and an increase in profitability to 18%-20% for enterprises with hybrid strategies. For example, Chumak, a company that already combines conventional methods with digital tools, has a profitability of 18%. Thus, a systematic approach to adapting international practices, a focus on innovation, environmental strategies, and strategic cooperation will be key to transforming the local advantages of the Mykolaiv region into global competitive advantages.

► Discussion

The findings of the study showed that digital marketing strategies, specifically the use of artificial intelligence and Big Data analytics, are the most effective for improving the competitiveness of food industry companies. These findings were consistent with those of S. Kaggwa *et al.* (2024), who found that integrating artificial intelligence into decision-making processes optimises costs and increases the profitability of business strategies. For example, in the case of Nestlé, the use of artificial intelligence helped reduce marketing research costs by 18%, highlighting the potential of technology for companies in the Mykolaiv region. M. Asikin *et al.* (2024) obtained analogous findings, where digital marketing was identified as a key factor in increasing the competitive advantages of small and medium-sized enterprises. This confirmed that even limited resources can be used effectively thanks to innovative tools.

The significance of environmentally-oriented strategies identified in the present study found its confirmation in the study by M. López-Cabarcos *et al.* (2024). The researchers noted that the implementation of sustainable resource management practices positively correlates with the financial performance of food companies. For instance, Danone's practices in reducing its environmental footprint by 30% confirmed that investments in the circular economy can provide long-term competitive advantages, especially in European markets. These findings were supported by T. Bjørndal *et al.* (2024), who considered aquaculture as a tool for ensuring food security through the rational use of resources. For the Mykolaiv region, this could mean the opportunity to develop niche products such as organic oils or juices that are in line with global sustainability trends.

An analysis of the effects of marketing processes on business performance conducted by A. Asslouni & S. Bourroubey (2025) reinforced the need for a systematic approach to strategy planning. The study found that combining conventional methods with digital tools (e.g., CRM

systems) can increase profitability by up to 18%, which is consistent with findings on the effectiveness of hybrid strategies. However, the limited budgets of local enterprises necessitate prioritising investments, particularly in automation and data analytics. This was confirmed by I. Sutaguna *et al.* (2023), who found that adapting marketing strategies to local conditions is critical for increasing sales. For example, Chumak achieved a profitability of 18% by combining CRM systems and local fairs, illustrating the effectiveness of a hybrid approach.

Compared to international practices, the findings of the present study highlighted the specific regional conditions of the Mykolaiv region, particularly its dependence on seasonality and limited logistics capabilities. M. Padhiary (2025) emphasised that collaborative strategies between producers and distributors contribute to cost optimisation and the expansion of export potential, which is in line with recommendations for the creation of clusters in the Mykolaiv region. For example, Polish agro-clusters reduced logistics costs by 15%, which could serve as a model for the region (UN Comtrade Database, n.d.).

The growing role of digital platforms in marketing, analysed by S. Asif (2025), demonstrated how the adaptation of online strategies can shape consumer preferences and ensure sustainable development. For example, the experience of McDonald's, described by A. Kusuma *et al.* (2024), illustrated the effectiveness of targeted social media campaigns in attracting young audiences. For businesses in the Mykolaiv region, this means an opportunity to increase online sales through the integration of analogous approaches, as confirmed by L. Sanbella *et al.* (2024) in their study on e-commerce optimisation.

I. Tomashuk (2023) emphasised the need to improve the competitiveness of agricultural enterprises through innovative business models, which is consistent with data on the significance of technological adaptation. Analogously, M. Madhavan *et al.* (2024) emphasised the role of Industry 5.0 in ensuring the sustainable development of small and medium-sized enterprises, especially in the context of the integration of cyber-physical systems. This highlighted the need for investment in modern technologies for enterprises in the region, particularly in logistics and resource management, as suggested by T. da Silva & S. Sehnem (2025). For example, the use of the Internet of Things for supply chain monitoring can reduce costs by 10%-15%, which is critical for enterprises with limited budgets.

T. Dildora (2024) focused on the organisational structure and management of food industry enterprises. The researcher noted that effective organisation of work processes is key to improving productivity and adapting to market changes. This is consistent with the findings on the need to implement CRM systems and automation, as organisational innovations directly affect operational efficiency. For instance, optimising internal communications and inventory management can reduce costs by 10%-12%, which is critical for companies with limited resources. S. Handoyo *et al.* (2023) noted that competition stimulates innovation in business strategies, confirming the value of flexibility and adaptation for enterprises in the Mykolaiv region. For example, competition with imported products forced local companies to focus on quality and environmental friendliness, which became their unique advantage.

K. Łukiewska (2024), using the example of Polish companies, emphasised the role of competitive potential in shaping international competitiveness, which is relevant for enterprises seeking to integrate innovation into their strategies. For the Mykolaiv region, this may mean the need to certify products according to international standards, such as EU Organic, which will enable them to enter European markets. Olkom's practices showed that such investments can lead to a 20%-30% increase in product prices. Another prominent aspect is logistics management in unstable conditions. J. Wijnands *et al.* (2008) indicated that efficient logistics chains are a key factor in the competitiveness of the food industry. For the Mykolaiv region, which faces restrictions due to the blockade of sea routes, this means the need to develop alternative routes through EU countries such as Romania or Poland, which requires cooperation with international partners. Z. Simonović & B. Ilić (2024) highlighted that managing complex business systems in the agro-industrial complex requires the integration of technological and organisational solutions. E. Aisyah *et al.* (2025) pointed to a link between entrepreneurial orientation and the effectiveness of business strategies, which is particularly relevant for small enterprises that dominate the region's food industry. For example, enterprises that actively use digital tools for market analysis demonstrate a higher response rate to changes in demand (Hasani *et al.*, 2023).

The findings of the present study were consistent with the conclusions of E. Boru *et al.* (2025), who emphasised that improving the competitiveness of agro-industrial enterprises is possible through the integration of marketing strategies with institutional coordination and support mechanisms. Using the example of Ethiopian industrial agro-parks, the researchers demonstrated that multi-level interaction between producers, logistics operators, and government structures contributed to the development of an effective export-oriented environment. This approach is also relevant for the Mykolaiv region, where the creation of cluster models and the development of public-private partnerships could be a key factor in strengthening the coordination of marketing activities, improving access to infrastructure, and simplifying entry into foreign markets. Specifically, the IT training programmes for managers proposed in the study could become part of state support for staff training, which is in line with the conclusions of B. Kuc *et al.* (2021), who, based on an analysis using the McKinsey matrix, substantiated the need for structural changes to achieve sustainable competitive advantages.

In the context of globalisation, N.E. Putri G & A. Aprianingsih (2025) proposed marketing strategies focused on creating unique local products, which is in line with the recommendations for developing organic and eco-friendly brands for the Mykolaiv region. For example, the creation of value-added products, such as functional food supplements based on local raw materials, could attract new markets (Berisha, & Rexhepi, 2022). Compared to the study by L. Thoan *et al.* (2024), which analysed the effects of competition on business strategies, the present findings emphasised that enterprises in the Mykolaiv region need flexibility in responding to external challenges, such as fluctuations in raw material prices or changes in

regulatory requirements. For example, growing demand for organic products in the EU creates opportunities but requires compliance with strict standards, which can be achieved through certification and innovation in production (Rama *et al.*, 2023). Thus, the findings of the present study are consistent with the conclusions of other researchers, confirming that a combination of innovative approaches, digital technologies, and effective resource management is crucial for improving the competitiveness of food industry enterprises.

► Conclusions

The study revealed that the competitiveness of food industry enterprises in the Mykolaiv region largely depends on the chosen marketing strategy, the degree of its digitalisation, adaptation to regional conditions, and the enterprise's capacity for institutional interaction. An analysis of three types of strategies – conventional, hybrid, and digital – showed the advantage of the latter: digital approaches demonstrated the highest ROI (18%-22%), profitability (20%-25%) and logistics efficiency (costs – 10%-12%). Hybrid strategies also showed stable outcomes (ROI 12%-15%, profitability 15%-18%), while conventional strategies were the least effective in all criteria (ROI 8%-10%, logistics costs up to 25%). A SWOT analysis supplemented the quantitative results, identifying critical factors that hinder the effective implementation of strategies. The most significant are the limited marketing budgets of small and medium-sized enterprises, the seasonal dependence of raw material supplies, and the insufficient level of digital literacy among management. At the same time, the availability of high-quality raw materials,

regional product identity, and consumer interest in niche eco-friendly products were identified as strengths.

The practical recommendations of the study include: 1) a gradual transition to digital marketing tools (CRM, Big Data analytics, contextual advertising); 2) the creation of regional clusters to improve logistics efficiency and stability of raw material supplies; 3) the development of state support programmes for digital education for enterprise specialists. These measures will increase conversion rates by up to 15%, reduce marketing costs by up to 10%, and improve the market position of products in both internal and external markets. The limitations of the present study included the lack of dynamic indicators for several marketing cycles, which did not allow for a full assessment of the long-term sustainability of individual strategies, as well as the insufficient representativeness of microenterprise data due to their low level of public reporting. Further research should focus on analysing the effects of marketing strategies in terms of product niches, expanding the sample of enterprises, and investigating integration models within the framework of state cluster policy, which could become a key factor in the sustainable growth of the regional food industry.

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Економічний аналіз маркетингових стратегій для підвищення конкурентоспроможності підприємств харчової промисловості в агропромисловому комплексі

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► **Анотація.** Метою дослідження було проаналізувати маркетингові стратегії підприємств харчової промисловості Миколаївської області задля підвищення їх конкурентоспроможності. У процесі роботи вивчено економічний стан харчової галузі регіону, проаналізовано поточні практики маркетингу та проведено оцінку конкурентного середовища. Використано широкий спектр методів, зокрема статистичний аналіз, SWOT-аналіз, метод бенчмаркінгу, а також економіко-математичне моделювання для прогнозування попиту на продукцію. На основі офіційних статистичних даних, практичних прикладів місцевих підприємств («Олко», «Чумак») і світових маркетингових практик (Nestlé, Unilever, Coca-Cola, Danone) визначено сильні та слабкі сторони підприємств регіону, а також можливості для розвитку. З'ясовано, що ключовими перевагами є доступ до якісної сировини, регіональна впізнаваність брендів і потенціал для використання цифрових технологій. Основними викликами є обмеженість маркетингових бюджетів, залежність від сезонності та висока конкуренція з боку великих національних і міжнародних виробників. Розроблено рекомендації для адаптації маркетингових стратегій до специфіки регіону, зокрема використання локальних переваг (географічне положення, доступ до ресурсів), впровадження сучасних інструментів маркетингу, покращення взаємодії між фермерами та підприємствами харчової промисловості, а також створення кластерів для підвищення ефективності. Запропоновано використовувати світовий досвід для розробки програм сталого розвитку, створення унікальних локальних продуктів і впровадження інновацій у дистрибуцію та логістику. Результати дослідження можуть бути використані підприємствами харчової промисловості Миколаївської області для оптимізації маркетингових стратегій, підвищення конкурентоспроможності та зміцнення позицій на внутрішньому і зовнішньому ринках

► **Ключові слова:** бізнес; сільське господарство; вторинний сектор; методи управління; рентабельність збуту



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Using sustainable development strategies to increase the competitive advantages of agricultural enterprises

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► **Abstract.** This study aimed to analyse the impact of sustainable development strategies on enhancing the competitiveness of agricultural enterprises in order to achieve economic efficiency under modern market conditions. The research methodology was based on a quantitative analysis of statistical indicators relating to the implementation of the circular economy, the use of renewable energy sources in agriculture, and state support for agricultural research in European Union countries. Key environmental initiatives of the European Union, such as the Common Agricultural Policy and the Circular Economy, and their relevance to agricultural businesses were examined. In the course of the research, the successful experiences of Denmark, Sweden, the Netherlands, Germany, and France in implementing sustainable agricultural practices were analysed. The study investigated the implementation of sustainable development in the agricultural sector of both Ukraine and the European Union, particularly through an analysis of the practices of two companies: Rheinisch-Westfälisches Elektrizitätswerk (Germany) and Astarta-Kyiv (Ukraine). The results of the study indicated that Rheinisch-Westfälisches Elektrizitätswerk invested over 5 billion euros in the expansion of renewable energy sources between 2019 and 2024, particularly in agrovoltatics and bioenergy, enabling the company to reduce carbon dioxide emissions by 50% by 2030. Meanwhile, Astarta-Kyiv invested over 5 million euros in irrigation systems and expanded biogas production in 2023-2024, which contributed to increasing the enterprise's energy independence and enhancing its export potential. Based on the

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findings, recommendations were developed for Ukraine regarding the integration of sustainable development into the agricultural sector, including: increased investment in renewable energy, expansion of bioenergy capacities, digitalisation of agricultural production, improved state support for sustainable initiatives, and the adaptation of legislation to the environmental standards of the European Union

► **Keywords:** circular economy; renewable resources; digitalisation; environmental friendliness; international experience

► Introduction

In the context of globalisation and heightened competitive pressure, agricultural firms must create effective procedures for achieving sustainable development. A fundamental method to attaining enduring success is the adoption of sustainable development policies that harmonise economic efficiency, environmental protection, and social accountability. These solutions not only mitigate environmental harm but also generate new potential for augmenting the competitive advantages of firms in the agricultural industry. Conventional approaches to agricultural business are becoming progressively inadequate for long-term effectiveness (Khrystenko *et al.*, 2025). The Intergovernmental Panel on Climate Change (n.d.) reports that the average global temperature has risen by roughly 1.5°C since the pre-industrial era, resulting in extreme weather events, droughts, and alterations in precipitation patterns, notably affecting agriculture. Moreover, consumers are progressively preferring items produced with low environmental impact, necessitating agricultural firms to modify their business models. The implementation of sustainable development plans is increasingly essential for environmental and economic reasons, serving as a critical determinant of competitiveness, facilitating access to international markets and “green” finance.

The research topic is that, despite increasing interest in sustainable development, numerous agricultural firms face challenges in its implementation. This results from several issues, including inadequate awareness among managers regarding the advantages of sustainable growth, elevated initial expenses linked to environmental and social efforts, and the absence of effective state support systems. Furthermore, it is essential to tailor worldwide experiences in executing sustainable strategies to the unique circumstances of the Ukrainian agriculture sector.

The subject of sustainable agricultural enterprise development has garnered considerable interest from scholars who have analysed diverse facets of its execution and its influence on competitiveness. J. Murphy & A. Gouldson (2020) shown that companies incorporating environmental management principles into their operations successfully reduced production costs by optimising resource use. Their findings substantiate the assertion that sustainable development functions not only as a mechanism for guaranteeing environmental safety but also as a method for improving economic efficiency. T. Gorokhova *et al.* (2023) examined the European experience in adapting the agriculture sector to sustainable development objectives, identifying state subsidies and preferential lending as critical success factors. They underscored that, without enough governmental assistance, enterprises-especially small and medium-sized ones-cannot execute long-term sustainable development objectives.

Research conducted by J. Clapp & S.L. Ruder (2020) demonstrated that the implementation of precision agriculture and digital technologies can markedly diminish environmental impact while concurrently enhancing enterprise efficiency. The authors noted that investments in novel solutions generally produce returns within a few years due to improved production efficiency. S. Fortunati *et al.* (2020) made a notable contribution to the examination of the social aspect of sustainable development by analysing the influence of corporate social responsibility on the positive perception of agricultural firms. They proved that enterprises involved in social activities get competitive advantages through enhanced trust from consumers and partners.

O. Dovgal *et al.* (2024) examined the correlation between the adoption of sustainable practices and the financial viability of agricultural firms. Their findings suggest that companies employing a systematic method for implementing environmental and social initiatives exhibit greater long-term profitability. A. Sartal *et al.* (2014) noted that consumers are progressively favouring products produced in alignment with environmental responsibility concepts. Their research validated that sustainable development can function as a mechanism for product differentiation in the marketplace.

A. Appolloni *et al.* (2022) examined the challenges associated with organic product certification and its influence on business competitiveness. Companies with worldwide environmental quality certifications markedly increased their export prospects. Y. Majeed *et al.* (2023) investigated the significance of investing in renewable energy sources in the agriculture industry. They determined that businesses utilising biogas facilities or solar panels not only decrease operational expenses but also produce supplementary revenue by selling excess energy.

N. Siebrecht (2020) examined the obstacles to the execution of sustainable development plans in agricultural firms. He observed that the principal impediments comprise a lack of environmental awareness, inadequate finance, and a deficiency of skilled professionals in this domain. M. Habib-Ur-Rahman *et al.* (2022) examined the effects of global climate change on agricultural management and affirmed the imperative of adopting adaptive management systems. Their observation indicates that the implementation of sustainable development principles allows agricultural firms to mitigate risks linked to harsh weather conditions.

Researchers affirm that sustainable development is crucial for improving the competitiveness of agricultural operations; yet, its execution necessitates a comprehensive approach that includes innovative technology, social responsibility, and governmental backing. However, there

is an absence of thorough research regarding the mechanisms for adapting international experiences to Ukrainian contexts, assessing the economic viability of long-term investments in sustainable technologies, and investigating the contribution of small and medium-sized enterprises to the sustainable development of the agricultural sector. A comprehensive review of the mechanisms for governmental promotion of environmental initiatives and the effects of sustainable strategies on business development is required.

This study aimed to evaluate the fundamental mechanisms for executing sustainable development strategies within agricultural firms and their impact on competitive advantages. The study objectives were: to analyse current methods for implementing sustainable development strategies in the European Union's agricultural sector; to evaluate the influence of state support and international investment on sustainable agriculture; and to assess the impact of sustainable development on the competitiveness of agricultural enterprises to formulate practical recommendations for effective integration of these principles.

► Materials and methods

The research utilised an extensive integration of quantitative and qualitative studies to evaluate the influence of sustainable development on the agricultural sector's competitiveness. To this end, comparative analysis methodologies and a systems perspective were utilised, enabling a comprehensive evaluation of the integration of environmental and new technology in agriculture. The primary statistical data were sourced from official entities, notably Eurostat (n.d.), which offers insights into critical indicators including the rate of circular material utilisation in European Union nations, the volume of electricity consumption derived from renewable sources in agriculture, and governmental support for agricultural research and development from 2019 to 2023. The data for 2024 had not been released at the time of the study.

A quantitative study was performed to evaluate patterns among EU countries, facilitating the identification of dynamics in the transition to a circular economy, the efficacy of renewable energy deployment, and the extent of public support for research in sustainable development. A comparative analysis of the policies of Denmark, the Netherlands, Germany, France, and Sweden facilitated the identification of the most efficacious public mechanisms for promoting environmental initiatives, notably including the Common Agricultural Policy (CAP) (n.d.), the programme "A New Circular Economy Action Plan" (Communication from the Commission..., 2020), and the European Green Deal (n.d.). These countries were chosen for their prominent roles in advancing sustainable development within the agricultural sector and their integration of cutting-edge environmental technologies. The research examined several EU efforts designed to promote sustainable agricultural development, including the Biodiversity Strategy for 2030 (n.d.), the Farm to Fork Strategy (n.d.), and the Ecophyto Plan II (2015). These programmes are crucial for enforcing environmental standards, enhancing the efficiency of natural resource utilisation, and mitigating the environmental impact of agriculture.

A case study method was utilised to examine the influence of sustainable development on the competitive advantages of enterprises, focussing on the activities of two companies: Rheinisch-Westfälisches Elektrizitätswerk (RWE) (2025) (Germany) and Astarta-Kyiv Agro-Industrial Holding (n.d.) (Ukraine). RWE was identified as a leader in the implementation of agrovoltatics and bioenergy, granting the company access to international financing and strategic collaborations in renewable energy. Astarta-Kyiv is a Ukrainian enterprise that promotes sustainable development by utilising biogas plants, precision agriculture, and efficient water conservation systems, therefore enhancing the company's energy independence and export capacity. The investigation utilised business reports, strategic documents, and environmental activities from 2019 to 2024, facilitating a comparison of ecological transformation strategies in the EU and Ukraine.

A systems approach was employed to evaluate the interconnections among economic, environmental, and social dimensions of sustainable development. The research examined the impact of state regulation, investment policy, and international financing on the efficacy of environmental projects. Special emphasis was placed on the function of international groups and financial initiatives designed to promote the circular economy, advance renewable energy, and facilitate the digitisation of agricultural production. The research included statistical data analysis, comparative assessment of state policies, and scrutiny of corporate strategies, enabling the identification of critical criteria that facilitate the effective implementation of sustainable development in the agricultural sector. This interdisciplinary approach facilitated a thorough comprehension of ecological change processes and allowed for the formulation of pragmatic recommendations for Ukraine.

► Results

Modern approaches to implementing sustainable development strategies in the agricultural sector. Sustainable development has arisen worldwide as a fundamental framework for economic progress, seeking to attain a healthy equilibrium of economic efficiency, social equality, and environmental stewardship. The agricultural sector, a major consumer of natural resources and a key contributor to environmental impact, need the immediate incorporation of sustainable development concepts to guarantee long-term food security, economic resilience, and ecological stability. The notion of sustainable development was officially articulated in the Report of the World Commission on Environment and Development (n.d.), which characterised it as development that fulfils the requirements of the current generation without jeopardising the capacity of future generations to satisfy their own needs. In 2015, the United Nations General Assembly ratified the Sustainable Development Goals, encompassing 17 fundamental domains for advancement by 2030 (Tomislav, 2018). The primary objectives for the agricultural sector encompass: eliminating hunger and fostering sustainable agri-food systems; ensuring the judicious utilisation of water resources and mitigating water pollution; incorporating clean energy into agricultural practices; advocating for sustainable consumption and production; and tackling climate change by decreasing greenhouse gas emissions and adapting to evolving climatic conditions.

The agriculture industry encounters various issues that require the implementation of sustainable development concepts. These encompass soil degradation, biodiversity loss, natural resource depletion, climate change, and the environmental repercussions of the war in Ukraine, including land and water contamination from explosives and military waste (Zavhorodnii *et al.*, 2024). A fundamental strategy for integrating sustainability in agriculture is the circular economy, a framework focused on waste reduction, resource reutilisation, and the shift from a linear production model (“production – consumption – disposal”) to closed-loop systems, where byproducts are perpetually repurposed. The circular economy in agriculture is implemented via composting

and biogas technologies that transform organic waste into fertilisers and energy; the use of agricultural residues, such as straw and corn husks, for biofuel production; and efficient water management, facilitated by water collection and reuse technologies (Velasco-Muñoz *et al.*, 2022). The experiences of European nations illustrate the considerable efficacy of this paradigm. The circular material use rate, which quantifies the percentage of reused and recycled resources relative to total material intake, serves as a key indicator of success in this domain (Table 1). This data is crucial for comprehending how various nations are embracing the ideas of the circular economy and utilising renewable resources to alleviate environmental impacts.

Table 1. The rate of use of cyclical material in EU countries for 2019-2023, %

	2019	2020	2021	2022	2023
EU	11.2	11.2	11.1	11.5	11.8
Austria	11.5	11.4	11.3	12.4	14.3
Belgium	20.5	22.9	21.4	18.3	19.7
Denmark	7.6	7.6	8.6	9.3	9.1
Spain	9	9.3	8.8	9.4	8.5
Italy	18.8	20.6	19.7	20.6	20.8
Netherlands	25.6	27.1	28.5	27.2	30.6
Germany	12.4	12.8	12.2	12.5	13.9
Poland	9.2	7.4	7	6.7	7.5
France	17.1	16.2	15.9	17.5	17.6
Sweden	6.4	6.9	9.5	12.1	9.9

Source: created by the authors based on Eurostat (n.d.)

The Netherlands demonstrates the highest figures, with an increase from 25.6% in 2019 to 30.6% in 2023, indicating the effective implementation of circular economy practices. In contrast, Sweden, after a notable rise in 2022, shows a slight decline in 2023 to 9.9%. Other countries, such as Germany, France, and Italy, exhibit a steady upward trend, with Germany increasing from 12.4% in 2019 to 13.9% in 2023. The progress observed across most countries reflects the gradual adoption of more efficient technologies for incorporating recycled materials into production processes. The shift to renewable energy sources signifies a

crucial aspect of sustainable agricultural development. Agriculture possesses considerable potential for solar energy utilisation via the installation of solar panels on rooftops of farms and agricultural structures, wind energy through the deployment of wind turbines in climatically appropriate areas, and bioenergy through the transformation of agricultural waste into biofuels. These approaches allow farmers to diminish their dependence on conventional energy sources (Rahman *et al.*, 2022). Table 2 displays information regarding electricity consumption derived from renewable sources within the agricultural sector.

Table 2. Electricity consumption volume from renewable sources in the agricultural sector across EU countries, 2019-2023 (GWh)

	2019	2020	2021	2022	2023
EU	35,377.9	36,487.8	38,797.8	37,847.4	36,064.6
Austria	1,884.2	1,831.2	2,149.8	2,033.7	1,985.0
Belgium	460.6	489.8	407.5	397.4	344.3
Denmark	628.1	610.5	660.2	638.0	638.5
Spain	831.1	829.5	828.9	856.0	833.5
Italy	619.1	611.9	880.7	864.8	795.4
Netherlands	4,008.0	4,418.4	4,718.8	4,631.0	3,548.9
Germany	8,940.0	9,510.4	9,702.4	9,619.1	9,374.4
Poland	5,549.2	5,677.3	6,732.6	5,500.7	5,083.8
France	4,162.7	4,482.9	4,533.3	4,506.0	4,968.3
Sweden	2,605.1	2,542.8	2,319.3	2,951.3	2,545.4

Source: created by the authors based on Eurostat (n.d.)

The total consumption of electricity from renewable sources in the EU demonstrates some fluctuation, decreasing from 38,797.8 GWh in 2021 to 36,064.6 GWh in 2023. However, certain countries exhibit either stable growth or fluctuations within specific ranges. For instance, France shows consistent growth in renewable energy consumption, reaching 4,968.3 GWh in 2023, indicating the active adoption of “clean” energy within the agricultural sector. The Netherlands, despite reporting a high level of renewable electricity consumption in 2021 (4,718.8 GWh), experienced a decline to 3,548.9 GWh in 2023, which may be attributed to structural changes in energy consumption patterns. Meanwhile, countries such as Poland maintain comparatively lower levels of renewable electricity consumption, potentially reflecting a slower integration of renewable technologies in agriculture relative to other EU member states.

Sustainable development includes environmental and economic aspects as well as the social responsibilities of

agribusiness, which involve investing in social infrastructure to support local communities, ensuring favourable working conditions for agricultural labourers, promoting food security, and enhancing access to eco-friendly products (Ali, 2023). In EU nations, governments actively endorse responsible agriculture by providing subsidies and grants to farmers who implement ecologically sustainable technologies. Investment in agricultural research and development is essential for fostering innovation that improves productivity, environmental sustainability, and resource efficiency. Government assistance for this study is essential for progressing the agricultural sector, especially for the execution of sustainable development strategies, the circular economy, and technological innovation (Sartas *et al.*, 2020). Each EU nation allocates research funds variably, mirroring their distinct economic capabilities and political approaches to advancing the agro-industrial sector. Table 3 illustrates the magnitude of governmental assistance for agricultural research and development.

Table 3. Government assistance for agricultural research and development in EU nations, 2019-2023 (million EUR)

	2019	2020	2021	2022	2023
EU	2,961.1	3,217.9	3,337.7	3,576.3	3,643.1
Austria	36.1	39.3	51.0	61.9	94.6
Belgium	57.0	58.5	78.7	71.7	86.1
Denmark	101.8	90.5	139.1	160.2	95.4
Spain	449.0	472.6	499.7	519.1	543.3
Italy	141.6	219.0	219.6	364.1	420.7
Netherlands	917.5	1,028.5	1,121.6	1,112.4	1,092.7
Germany	97.3	145.0	4.3	5.3	7.0
Poland	362.2	369.5	354.8	429.8	492.5
France	45.7	49.2	79.6	78.7	49.4
Sweden	2,961.1	3,217.9	3,337.7	3,576.3	3,643.1

Source: created by the authors based on Eurostat (n.d.)

The total amount of support in the EU increased from EUR 2,961.1 million in 2019 to EUR 3,643.1 million in 2023, indicating a growing emphasis on innovation in agriculture. The Netherlands traditionally receives the largest share of funding, with EUR 1,092.7 million allocated in 2023, reflecting the country's highly developed agricultural technology sector. A notable increase in investment is observed in Italy, where funding rose nearly threefold – from EUR 141.6 million in 2019 to EUR 420.7 million in 2023. Conversely, Germany has experienced a sharp decline in funding levels in recent years, which may suggest a re-evaluation of state priorities concerning agricultural research support. Meanwhile, countries such as Poland and Spain demonstrate a steady rise in funding, indicating sustained governmental interest in the long-term development of agriculture through scientific advancement.

Government support and international initiatives in the field of sustainable development. The European Union is a global frontrunner in enacting ecologically sustainable laws and regulations designed to diminish emissions, encourage the judicious use of resources, and foster a circular economy in agriculture. The main aim of these activities is to establish an agricultural sector that integrates high production with low environmental impact, efficient utilisation of natural resources, and

enhanced food security (Cifuentes-Faura, 2022). The EU strategy focusses on long-term results, designating agriculture as a crucial sector for climate change mitigation and ecological preservation.

A primary strategic endeavour in this area is the European Green Deal (n.d.), which establishes a cohesive framework for sustainable development across all economic sectors, including the agro-industrial complex. The text delineates a gradual shift towards a climate-neutral economy by decreasing reliance on fossil fuels, minimising greenhouse gas emissions, and fostering the advancement of innovative environmental technologies. The agricultural sector is recognised as a key area necessitating reform to reduce its environmental impact. The Farm to Fork Strategy (n.d.) is a fundamental element of the EU's sustainable development agenda, aiming to reform the food system and reduce the environmental effect of agriculture. It encompasses objectives like a 50% decrease in chemical pesticide usage, a 20% reduction in mineral fertiliser application, and an elevation of organic farming to 25% of the total agricultural land area. The policy prioritises the digitisation of agriculture, incorporating artificial intelligence, satellite surveillance, and blockchain technologies to improve resource efficiency and mitigate environmental impact (MacPherson *et al.*, 2022).

Another key initiative is the Biodiversity Strategy for 2030 (n.d.), which forms part of the European Green Deal and focuses on protecting ecosystems and restoring natural landscapes vital for agricultural productivity. Core measures include the establishment of ecological corridors, the protection of pollinators, and the rehabilitation of degraded land. Particular attention is given to agroforestry – the integration of agricultural land with forest plantations – which helps reduce soil erosion, improve soil fertility, and restore essential ecosystem services.

The EU's CAP (n.d.) is one of the most substantial instruments supporting the agricultural sector, offering financial assistance to agricultural producers and facilitating their transition towards more environmentally responsible business models. In the 2023-2024 period, the CAP underwent significant changes, placing greater emphasis on sustainable development and the adaptation of agriculture to the challenges posed by climate change. An "eco-scheme" mechanism was introduced to provide financial incentives for farmers who comply with enhanced environmental standards. Key requirements include the reduction of agrochemical use, expansion of organic farming areas, implementation of cover crops, and the preservation of natural landscapes. Additionally, stricter requirements have been introduced for efficient water management and the reduction of greenhouse gas emissions.

The EU advocates for resource reutilisation, waste reduction, and the advancement of biotechnologies in agriculture as outlined in the New Circular Economy Action Plan (Communication from the Commission..., 2020). Special emphasis is placed on technologies that transform organic waste into biofuels, fertilisers, and feed additives. There is a focus on facilitating the generation of biogas, bioethanol, and biodiesel, thereby diminishing the agriculture sector's dependence on fossil fuels. These efforts not only bolster the energy autonomy of rural areas but also promote the economic stability of agricultural enterprises.

Successful implementation of these initiatives can be observed in countries such as Denmark, the Netherlands, Germany, France, and Sweden. Denmark serves as a prominent example of effective environmental integration in agriculture. In November 2024, Danish political parties reached an agreement to convert 10% of agricultural land into forests and plant one billion trees. This initiative involves allocating 43 billion Danish kroner (USD 6.1 billion) to purchase land from farmers for project implementation. The objective is to restore natural ecosystems and reduce greenhouse gas emissions, thereby addressing global warming (Pavlyuk, 2024). In addition, Denmark has introduced a unique action plan aimed at transitioning to a more plant-based food system. In 2021, the government allocated approximately USD 200 million to support this transition, of which USD 85 million was directed to plant-based farmers. The remaining funds supported projects such as renovating cafeterias to encourage plant-based consumption and establishing incubators for plant-based start-ups. This approach has gained widespread support due to its emphasis on business opportunities and environmental benefits, rather than imposing restrictions on meat consumption (Torrella, 2024).

The Netherlands is a frontrunner in the implementation of innovative approaches to sustainable agriculture.

The country is actively developing vertical farming and precision agriculture, both of which reduce water and chemical fertiliser use while increasing yields. These technologies contribute to the optimisation of land use and the reduction of the agricultural sector's environmental impact. According to the Dutch Biogas Association, the Netherlands produced over 1.5 million m³ of biogas per day in 2023, enabling a reduction in CO₂ emissions by 5.4 million tonnes per year. The country has set an ambitious target to increase biogas production by 30% by 2030 (Platform Groen Gas, n.d.). The Netherlands also actively supports circular economy programmes focused on resource reuse and reducing food waste. As part of the National Circular Economy Plan, the country aims to cut food waste by 50% by 2030 and achieve a complete cycle of organic waste recycling for reuse in agriculture. Statistics from 2022 indicate that approximately 60% of organic waste produced in the agricultural sector was either converted into energy resources or used as fertiliser (Ministry of Infrastructure and Water Management, 2023).

Germany is actively applying circular economy ideas in the agro-industrial sector, facilitating the repurposing of organic waste for the generation of bioethanol, biogas, and biodiesel. In 2024, the German government sanctioned the disbursement of EUR 57.6 billion for "green" initiatives, reflecting a 60.2% increase relative to 2023. Of this amount, EUR 18.9 billion is allocated for reconstruction and new construction subsidies, EUR 12.6 billion for renewable energy sources, and EUR 4.7 billion for the expansion of electric vehicle charging infrastructure. These investments seek to facilitate the nation's objective of attaining carbon neutrality by 2045 (Nynko, 2023). Germany is actively implementing precision farming technologies in agriculture, utilising drones and sensors to assess soil and crop conditions. These advances diminish the need on chemical fertilisers and water while enhancing the efficiency and sustainability of agricultural output.

France ranks among the EU leaders in ecological and sustainable agricultural practices. In 2020, the country launched the Ecophyto Plan II (2015), aimed at reducing pesticide use in agriculture by 50% by 2025. Under this programme, farmers receive subsidies to purchase environmentally friendly plant protection products. France also supports the transition to organic farming, with a target of allocating 15% of all agricultural land to organic production by 2025. In 2024, new standards were introduced to encourage biodiversity preservation and the restoration of degraded lands. France is also heavily investing in sustainable farming technologies, including precision agriculture systems that minimise resource use. Moreover, the country employs innovative food production methods that help reduce food waste and conserve energy resources (Jacquet *et al.*, 2022).

Sweden excels in the adoption of sustainable agricultural techniques, systematically incorporating eco-friendly technologies into its agricultural industry. A significant endeavour is the Farmers for Climate approach, which seeks to diminish greenhouse gas emissions in the sector. Sweden aims to attain net-zero greenhouse gas emissions in agriculture by 2045, in alignment with its national policy for executing the Paris Climate Agreement (Marinsson & Hansson, 2021). In recent years, the nation has

markedly augmented the utilisation of renewable energy sources in agricultural production, especially through the manufacture of biogas, bioethanol, and biodiesel from agricultural waste. In 2020, Sweden attained a 16% contribution of bioenergy to its overall national energy production, encompassing energy sourced from agricultural waste. Moreover, over 40% of Swedish farmers utilise advanced precision agriculture technologies, facilitating reductions in fertiliser application and limiting environmental effect (At a glance..., 2024).

The agricultural sector of Ukraine is a vital element of the national economy, guaranteeing food security, considerably contributing to gross domestic product (GDP), and representing a considerable portion of exports. In 2024, agricultural exports totalled around USD 24.5 billion (Tarasovsky, 2025). Nevertheless, under prevailing circumstances, the industry encounters multiple obstacles that impede sustainable development. The issues encompass the repercussions of warfare, environmental deterioration, inadequate investment in contemporary technology, a little degree of digitalisation, and inefficient governmental regulation concerning green transformation. Ukraine has significant potential to implement sustainable development concepts, which might improve the competitiveness of its agriculture sector in domestic and international markets.

A pivotal element of the present condition of sustainable development in agricultural enterprises is the incremental adoption of environmental practices, including organic farming, the reduction of chemical fertilisers and pesticides, precision farming technologies, and the shift to renewable energy sources. Notwithstanding the increasing interest in sustainable development, the rate of adaptation is sluggish, chiefly attributable to insufficient financial assistance for farmers, a fragile regulatory framework, and an unstable socioeconomic landscape. Numerous Ukrainian firms, especially small and medium-sized ones, lack the requisite resources to adopt environmental innovations, hindering the shift to sustainable production methods (Manushkina *et al.*, 2024).

A major concern is the impact of military activities, resulting in substantial environmental degradation, destruction of agricultural infrastructure, mine contamination, and damage to land reclamation systems. Estimates from the Kyiv School of Economics suggest that Ukraine's agricultural sector may incur indirect losses up to USD 83 billion by the conclusion of 2025. These losses are associated with decreased seeded areas and alterations in

production technologies, which adversely impact crop yields. The yield of grains and oilseeds decreased from 107 million tonnes in 2021 to roughly 77 million tonnes in 2024. The conflict has additionally limited farmers' access to contemporary technology, fertilisers, and seeds, hence diminishing yields and product quality (Ukraine farm sector..., 2024). Ukraine is predicted to incur an annual GDP loss of USD 11 billion owing to mine contamination, rendering 2.5% of fertile land unproductive (Harmash, 2024).

Financial assistance and investment in sustainable development are essential. Although several initiatives, including grant programmes from international organisations, are in progress, their magnitude is now inadequate to effectuate a systemic impact on the sector. The inadequate digitisation of agriculture is a challenge. The implementation of digital technology, including satellite monitoring and precision agriculture, has the potential to significantly decrease the consumption of natural resources and alleviate environmental effect. Nonetheless, the execution of such solutions necessitates the requisite skills and technical infrastructure, which are predominantly available to major agricultural enterprises. Conversely, small and medium-sized farmers frequently lack access to these innovations.

Despite the challenges outlined, Ukraine possesses considerable potential for transitioning to a sustainable agricultural model. Engagement in European environmental initiatives, integration into EU funding programmes, and the adaptation of national legislation to align with European environmental standards could become key drivers in accelerating the country's "green" transformation. Furthermore, the promotion of local initiatives focused on expanding organic farming, enhancing energy efficiency, and implementing circular economy principles will be vital to fostering long-term sustainable development.

The influence of sustainable development on the competitiveness of agricultural operations. Sustainable development is a significant factor influencing the competitiveness of the agricultural sector, as demonstrated by the cases of two companies: Rheinisch-Westfälisches Elektrizitätswerk (RWE) (2025) in Germany and the As-tarta-Kyiv Agro-Industrial Holding (n.d.) in Ukraine. RWE is actively engaged in the adoption of renewable energy technologies, particularly agrovoltatics – an innovative approach that integrates electricity generation with agricultural production. The company's key financial indicators are presented in Table 4.

Table 4. Key financial indicators of RWE, 2019-2024 (billion EUR)

	2019	2020	2021	2022	2023	2024 (3 rd quarter)
Income	13.1	13.7	24.5	38.4	28.6	15.9
Earnings before Interest, Taxes, Depreciation and Amortisation (EBITDA)	2.5	3.3	3.6	6.3	8.4	4
Profit	9.2	1.1	0.8	3	1.6	1.2
Assets	64.2	61.6	142.3	138.5	106.5	98.6
Equity	17.4	17.7	17	29.3	33.1	35.1

Source: created by the authors based on Rheinisch-Westfälisches Elektrizitätswerk (2025)

RWE's sustainable solutions have had a significant impact on its profitability, contributing to an increase in market share, the establishment of new partnerships, and

an enhanced corporate image. For instance, following a substantial expansion of its investments in renewable energy, the company's revenue almost doubled – from

EUR 13.7 billion in 2020 to EUR 24.5 billion in 2021 – and reached a record EUR 38.4 billion in 2022. In particular, agrovoltic and bioenergy projects have not only enhanced the efficiency of land use but also reduced energy costs, which positively influenced the company's EBITDA, rising from EUR 3.3 billion in 2020 to EUR 6.3 billion in 2022. However, in 2023, these figures declined, with profit falling to EUR 1.6 billion, attributed to the high initial costs associated with the implementation of new projects.

Renewable initiatives have become a key factor in reinforcing RWE's reputation as a leader in environmental responsibility, thereby facilitating the attraction of substantial international investments. For example, in 2023, the company secured over EUR 2.5 billion in "green" investments from the European Investment Bank and private partners to finance agrovoltic projects in Germany, Spain, and Italy. As a result, the company's equity increased from EUR 17.7 billion in 2020 to EUR 33.1 billion in 2023, indicating improved financial stability and heightened investor confidence.

Digital technologies have also significantly enhanced RWE's operational efficiency. The adoption of automated

monitoring and management systems for energy networks has enabled the company to reduce operating costs and optimise production. For instance, the application of artificial intelligence in electricity demand forecasting has improved resource management efficiency, which partially explains the growth in the company's EBITDA during 2022-2023. Moreover, the expansion of the agrovoltic project in Bavaria in 2023 enabled the production of up to 50 MW of electricity, supplying more than 30,000 households. This not only supported decarbonisation efforts but also boosted the company's profitability within the renewable energy sector.

Astarta-Kyiv, a prominent agro-industrial holding in Ukraine, is diligently incorporating sustainable development principles into its operations, emphasising the reduction of environmental impact and the enhancement of agricultural production efficiency. The corporation cultivates grain crops, sugar beets, milk, and various other agricultural products. The primary activities encompass the implementation of novel technology, enhancements in energy efficiency, and the advancement of organic agriculture. Table 5 delineates the company's principal financial metrics.

Table 5. Key financial indicators of Astarta-Kyiv, 2019-2024 (million EUR)

	2019	2020	2021	2022	2023	2024 (3 rd quarter)
Income	448	415.6	491.4	510.1	619.9	441.5
EBITDA	77.9	113.4	201.4	154.8	145.4	132.6
Profit	1.7	8.6	122.5	65.2	61.9	75.6
Assets	759.3	511.4	690.6	707.6	710.3	716.7
Equity	438.8	337.3	495.1	489.2	498.8	517.7

Source: created by the authors based on Astarta-Kyiv Agro-Industrial Holding (n.d.)

The implementation of sustainable development by Astarta-Kyiv has significantly influenced the company's financial performance and competitiveness. The transition to organic production, initiated in 2020 with 7,000 hectares and expanded to 11,500 hectares by 2023, enabled the company to enter the organic market, which offers higher added value and stable demand within the EU. This transition positively impacted financial performance: the company's revenue increased from EUR 415.6 million in 2020 to EUR 619.9 million in 2023, demonstrating the success of this strategy. Moreover, profitability improved markedly – with net profit rising to a record EUR 122.5 million in 2021 – driven by cost optimisation and the adoption of sustainable management practices.

A key contributor to the company's enhanced financial stability has been its strategy to increase energy efficiency. The implementation of bioenergy projects, including biogas plants, has significantly lowered energy costs, which is particularly important given the rising prices of conventional energy sources. As a result, the company's EBITDA following the launch of these programmes in 2021 reached EUR 201.4 million, and by 2024 (for the first three quarters) stood at EUR 132.6 million, indicating the effectiveness of this initiative. The use of precision agriculture and digital technologies – such as satellite

monitoring and automated systems for managing agricultural processes – has contributed to cost reductions in agrochemical use and optimised fertiliser application. This has not only lessened the environmental impact but also improved agricultural land productivity, thereby enhancing the profitability of crop production. Through these technological advancements, the company has achieved steady asset growth, from EUR 511.4 million in 2020 to EUR 716.7 million in 2024.

The attraction of international grants has also played a vital role in enhancing financial sustainability. For instance, in 2020, Astarta-Kyiv received a EUR 1.5 million grant from the EU for the development of sustainable agricultural technologies. These funds were allocated to the modernisation of production facilities and the implementation of environmental standards in line with contemporary European requirements. Such initiatives not only improved the company's environmental profile but also strengthened its market position, fostered partnership development, and enhanced its reputation as a responsible producer. Table 6 presents a comparative analysis of the approaches used in the implementation of sustainable practices. The differing strategies, investments, technologies, and environmental impacts adopted by these companies offer valuable insights for adapting similar approaches to the context of Ukraine.

Table 6. Comparison of RWE and Astarta-Kyiv in the implementation of sustainable practices

Criterion	RWE (Germany)	Astarta-Kyiv (Ukraine)
Branch	Energy, renewable energy, agrovoltatics	Agricultural production, processing, bioenergy
The main strategy for sustainable development	Investments in renewable energy sources, agrovoltatics, bioenergy	Biogas plants, precision agriculture, water conservation, energy efficiency
Investment in sustainable solutions	5+ billion euros in the period 2019-2023 for renewable energy and agrovoltatics	5+ million euros in irrigation in 2023 and 50 GWh in biogas plants in 2020
Impact on competitive advantage	Increasing access to “green” investments, international partnerships, growing market positions in the EU and abroad	Increasing export potential, improving energy independence and reputation in domestic and international markets
Main market	EU, international agroholdings, investors in “green” technologies	Ukraine, EU, international traders, agricultural companies
Environmental impact	Plans to reduce CO ₂ emissions by 50% by 2030, ensuring stable renewable energy production	Use of biogas, reduction of water consumption, minimisation of chemical load on soils
Financial support and subsidies	Benefits of European “green” investment programmes	Support from international financial organisations, subsidies for bioenergy and environmental projects
Digital technologies	Innovative platforms for energy consumption monitoring, process automation	Implementation of precision farming systems, digital monitoring of water and energy use
Future predictions	Continued development of agrovoltatics, bioenergy projects, and environmental initiatives	Development of biogas plants, organic farming, modernisation of irrigation systems

Source: created by the authors based on Rheinisch-Westfälisches Elektrizitätswerk (2025), Astarta-Kyiv Agro-Industrial Holding (n.d.)

Drawing from the experiences of firms like RWE and Astarta-Kyiv, some critical recommendations may be articulated for Ukraine to facilitate the adoption of sustainable practices in the agriculture sector. Ukraine ought to engage more vigorously in renewable energy sources and agrovoltatics. RWE's experience illustrates that the amalgamation of agricultural land with solar panels can effectively diminish CO₂ emissions while concurrently providing supplementary income for farmers. Ukraine has considerable potential for agrovoltaic development, which may simultaneously improve agricultural productivity and decrease reliance on traditional energy sources.

The proactive implementation of bioenergy technology, especially biogas facilities, is crucial. The experience of Astarta-Kyiv demonstrates that biogas is a useful means of reducing energy dependence and alleviating the negative effects of agricultural waste. Ukrainian agricultural firms ought to prioritise bioenergy development by assisting farms in the establishment of such facilities, which would enhance energy efficiency and create additional prospects for reducing greenhouse gas emissions.

An important domain is the implementation of precision agriculture technologies. Systems that provide precise fertiliser delivery and optimal water utilisation can markedly improve production efficiency. Ukraine ought to vigorously advance the evolution of digital technologies in agriculture, particularly through the adoption of Global Positioning System technologies, which facilitate the reduction of natural resource consumption and mitigate environmental impact. This will enhance agricultural yield without intensifying environmental strain.

Successful implementation of sustainable methods in agriculture necessitates support through government programmes, grants, and subsidies. Prioritising the financing of new and environmentally sustainable technologies for small and medium-sized farmers should be a governmental focus. These initiatives will guarantee wider access to emerging technology and promote the adaption

of businesses to sustainable development principles. A similarly significant facet is the overhaul of the legislative structure. Ukraine must persist in incorporating environmental efforts into national policy and implement legislative measures to promote sustainable development in the agricultural sector. This encompasses measures aimed at safeguarding water resources, conserving soil, rehabilitating damaged land, and mitigating environmental pollution. Ukraine may attain sustainable agricultural growth that adheres to environmental norms and aids in the conservation of natural resources for future generations just by addressing these concerns.

► Discussion

The study's results affirm that incorporating sustainable development principles into agricultural production is a crucial aspect in improving the competitiveness of agricultural firms. The industry currently confronts various issues, including as climate change, soil degradation, rising food consumption, and the necessity for the judicious utilisation of natural resources. Moreover, the implementation of sustainable technology has become imperative, not only for economic efficiency but also in reaction to increased worldwide environmental standards. A.S. Magdalena *et al.* (2025) investigated the influence of the circular economy on the financial performance of agricultural firms. They determined that closed production cycles, waste reutilisation, and other elements of the circular economy can substantially save operating expenses and enhance organisational resilience to market volatility. This study supports these findings and further examines the environmental aspects of the circular economy, namely its impact on diminishing pollution and enhancing resource efficiency. Innovations in agriculture, as evidenced by the research of A. Berxolli *et al.* (2023), can function as tools for economic sustenance and psychological stability for rural communities during crises, particularly among military conflicts.

The adoption of renewable energy is a vital aspect of sustainable agricultural development. Minimising dependence on fossil fuels allows agricultural businesses to reduce energy expenses, diminish greenhouse gas emissions, and adhere to contemporary environmental regulations (Musca & Kara, 2023). The deployment of solar panels, wind farms, and bioenergy facilities not only fosters energy independence for businesses but also bolsters their financial viability via access to assistance programmes and “green” investments. M.B. Pietrzak *et al.* (2021) performed an investigation on the economic feasibility of converting the agriculture industry to renewable energy sources. They determined that solar and wind energy are especially advantageous for substantial agrohholdings with adequate cash to invest in the requisite infrastructure. C. Cavicchi *et al.* (2022) contended that these technologies are predominantly unattainable for small and medium-sized firms owing to substantial initial expenses and prolonged return on investment durations. The present study affirms the importance of renewable energy, while emphasising that bioenergy technologies, especially biogas facilities, may be more attainable for medium-sized organisations.

Mitigating the adverse environmental effects of agriculture is attainable through the implementation of resource-efficient technology. Precision farming methods, computerised soil monitoring, and efficient water management reduce chemical inputs and improve agricultural output (Shahini *et al.*, 2023). For instance, minimising the application of synthetic fertilisers and pesticides not only mitigates pollution but also enhances the quality of agricultural products. L. Guo *et al.* (2022) examined the effects of diminished mineral fertiliser application on agriculture and discovered that, in the short term, this results in decreased yields, potentially harming enterprise profitability. Nonetheless, over the long term, enhancements in soil health resulted in heightened production efficiency. The present study acknowledges the significance of reducing chemical fertiliser usage while prioritising the equilibrium between environmental and economic considerations. It promotes the implementation of alternative methods, including precision agriculture and organic production.

J.M. Kwakye *et al.* (2024) examined the economic and environmental efficacy of bioenergy technology in agriculture, focussing specifically on biogas production from agricultural waste. He analysed the effects of biogas plant adoption on agricultural energy autonomy and the mitigation of greenhouse gas emissions. This study corroborates these conclusions, especially with the environmental advantages of bioenergy. Although J.M. Kwakye *et al.* emphasised bioenergy as a promising avenue, his study did not account for regional disparities in the viability of these technologies. The present analysis emphasises the significance of governmental assistance and legislative incentives to facilitate the broader implementation of bioenergy.

The advancement of sustainable farming methods is strongly affected by governmental policies and the level of support offered through national and international programmes. Government incentives, including subsidies for renewable energy, grant funding for scientific research in agro-innovation, and concessional loans for the adoption of environmentally sustainable technologies, promote a more vigorous transition of agricultural producers

to sustainable management practices (Bulgakov *et al.*, 2017; 2019). Moreover, international initiatives include the EU CAP (n.d.), the Horizon Europe (n.d.) programme, the Farm to Fork Strategy (n.d.), and the Biodiversity Strategy for 2030 (n.d.) significantly influence the establishment of global norms for sustainable development. These projects can act as standards for the modification of national agricultural policies. C.D. Thompson *et al.* (2022) examined governmental support programmes for environmental activities in agriculture, uncovering significant financial differences between Western and Eastern European nations. Their findings demonstrated that nations with elevated GDP per capita allocate significantly greater resources towards the advancement of the circular economy and green technologies. The present study reiterates the significance of state support while emphasising the efficacy of specific programmes, including Horizon Europe, the CAP, and the European Green Deal. Moreover, the current analysis examined both the magnitude of public investment and its allocation across small, medium, and big firms.

The application of digital technologies in agriculture is essential for advancing environmental sustainability and improving productivity. Automated management systems, artificial intelligence, the Internet of Things, and satellite monitoring provide accurate regulation of soil conditions, yield forecasting, resource optimisation, and the reduction of adverse environmental effects. The adoption of these technologies improves agricultural efficiency, lowers material expenses, and boosts the profitability of farming operations. Research by U. Deichmann *et al.* (2016) similarly revealed that firms that actively implement digital technologies can decrease fertiliser and water consumption, thus enhancing resource efficiency. The findings align with those of the current study; however, this analysis prioritises the environmental advantages of precision agriculture over its economic viability. Access to digital technologies varies markedly between nations.

Compliance with European environmental regulations allow firms to access cutting-edge technologies, funding opportunities, and global alliances (Silagadze *et al.*, 2024). Furthermore, compliance with stringent environmental requirements bolsters consumer confidence and reinforces the worldwide competitiveness of agricultural enterprises. J. Lu *et al.* (2020) examined the influence of compliance with environmental requirements on the export capacity of agricultural firms. Their findings indicated that enterprises aligning their manufacturing processes with European environmental standards experience markedly enhanced access to international markets, advantageous financing circumstances, and increased consumer trust. This study corroborates these conclusions, while also highlighting that international integration requires not just compliance with environmental regulations but also the modernisation of technological processes, frequently necessitating significant financial investment.

Sustainable agricultural growth is a complex process requiring a cohesive strategy and active collaboration among government, industry, and the scientific community. The adoption of renewable energy sources, precision agriculture technology, bioenergy solutions, digitalisation, and efficient resource management enhances firm competitiveness, ensures financial sustainability, and complies

with modern environmental norms. An integrated strategy for adopting sustainable practices is crucial for the long-term advancement of the agriculture sector, enhancing the economic performance of firms while concurrently mitigating the environmental impact of agricultural activities.

► Conclusions

The study's findings affirm that incorporating sustainable development into agriculture enhances enterprise competitiveness, economic resilience, and environmental accountability. The implementation of renewable energy sources, the digitisation of manufacturing, and the optimisation of resource utilisation allow enterprises to decrease operational expenses, attract further investment, and penetrate new markets. The adoption of digital technologies, especially satellite monitoring and automated systems, enables businesses to enhance resource efficiency, elevate product quality, and reduce environmental effect. The experience of EU nations illustrates that governmental assistance via grant programmes and tax incentives expedites the implementation of environmental projects.

An examination of RWE's financial metrics indicates that the company has proactively invested in renewable energy, favourably impacting its financial performance. From 2019 to 2023, RWE invested over EUR 5 billion in solar, wind, and bioenergy development, leading to a revenue increase from EUR 13.1 billion in 2019 to EUR 28.6 billion in 2023, and an EBITDA rise from EUR 2.5 billion to EUR 8.4 billion during the same timeframe. Astarta-Kyiv exhibits a beneficial effect from the adoption of bioenergy and precision agriculture. In 2020, the company

generated 50 GWh of biogas, thereby diminishing dependence on conventional energy sources. Investments in irrigation systems over EUR 5 million in 2023 facilitated enhanced water resource management, augmented crop production, and diminished environmental effect. These initiatives facilitated the company's profit increase from EUR 448 million in 2019 to EUR 619.9 million in 2023.

The successful execution of sustainable principles necessitates a holistic approach encompassing governmental backing, financial incentives, and innovative technologies. This approach will strengthen the agricultural sector's resilience, promote its integration into global markets, and foster the establishment of efficient and sustainable food systems for the future. A disadvantage of the study is its dependence on accessible statistical data and its failure to consider all elements affecting sustainable agricultural development, including regional particularities and changes in the political landscape. Future research may concentrate on a comprehensive investigation of the effects of particular environmental initiatives on the financial viability of agricultural firms and the efficacy of governmental support systems for sustainable agriculture.

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► **Анотація.** Робота була направлена на аналіз впливу стратегій сталого розвитку на підвищення конкурентоспроможності аграрних підприємств для досягнення економічної ефективності в умовах сучасного ринку. Методологія дослідження базувалася на кількісному аналізі статистичних показників щодо впровадження циркулярної економіки, використання відновлюваних джерел енергії в сільському господарстві та державної підтримки аграрних досліджень у країнах Європейського Союзу. Було розглянуто ключові екологічні ініціативи Європейського Союзу, такі як Спільна аграрна політика та Циркулярна економіка, їхнє значення для аграрного бізнесу. У процесі дослідження був проаналізований успішний досвід Данії, Швеції, Нідерландів, Німеччини та Франції щодо впровадження сталих аграрних практик. У роботі досліджено впровадження сталого розвитку в аграрному секторі України та Європейського Союзу, зокрема через аналіз практик двох компаній – Rheinisch-Westfälisches Elektrizitätswerk (Німеччина) та Астарта-Київ (Україна). Результати дослідження показали, що Rheinisch-Westfälisches Elektrizitätswerk інвестувала понад 5 млрд євро у розширення відновлюваних джерел енергії в період 2019-2024 рр., зокрема в агроvoltaїку та біоенергетику, що дозволило компанії зменшити викиди вуглекислого газу на 50 % до 2030 року. Водночас Астарта-Київ інвестувала понад 5 млн євро у системи зрошення та розширила біогазове виробництво за 2023-2024 рр., що сприяло підвищенню енергетичної незалежності підприємства та покращенню експортного потенціалу. На основі отриманих результатів розроблено рекомендації для України щодо інтеграції сталого розвитку в аграрний сектор, зокрема: активізація інвестицій у відновлювану енергетику, розширення біоенергетичних потужностей, цифровізація аграрного виробництва, удосконалення державної підтримки сталих ініціатив та адаптація законодавства до екологічних стандартів Європейського Союзу.

► **Ключові слова:** циркулярна економіка; відновлювальні ресурси; цифровізація; екологічність; міжнародний досвід



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Economic aspects of the introduction of renewable energy sources in the agro-industrial complex

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► **Abstract.** The aim of the study was to identify economic challenges to the introduction of renewable energy sources in the agricultural sector of Ukraine and to substantiate ways to overcome them, taking into account modern transformations. The methodological basis was formed by statistical analysis (in particular, trend and comparative), economic and legal analysis, as well as content analysis of scientific sources and regulatory documents. The study analysed current trends in the development of solar, wind and bioenergy in the agricultural sector. It has been established that the greatest economic effect is provided by projects based on the use of biomass, biogas and solar energy, which can reduce energy costs by up to 20-25% on average. It is found that bioenergy has the greatest prospects due to the significant amount of available agricultural raw materials; it is substantiated that the annual potential for replacing imported gas with biofuels is up to 5 billion cubic metres, which is equivalent to a reduction in costs of more than USD 2 billion. The article analyses the dynamics of solar energy implementation in the agricultural sector for the period 2018-2024, in particular, it is found that in the context of the armed conflict, the share of operating solar power plants decreased to 50-60% due to damage to infrastructure, but in the western and central regions there is a tendency to increase installed capacities. It has been found that the efficiency of the introduction of renewable energy sources depends on the level of

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government support, the availability of targeted instruments such as “green” tariffs, low-interest loans, and transparent regulatory mechanisms. The practical significance of the study is to provide recommendations for strengthening support for the introduction of renewable energy sources, which will contribute to the energy efficiency of the agricultural sector, increase the profitability of farms and the competitiveness of their products

► **Keywords:** innovative technologies; sustainable development; competitiveness; environmental sustainability; state support; investment incentives

► Introduction

The relevance of the study is stipulated by the need to develop effective economic mechanisms for the introduction of renewable energy sources (RES) in the agricultural sector, as this sector is the basis for ensuring food security, economic stability and environmental balance. Climate change, the energy crisis, rising costs of traditional energy sources and international environmental obligations require countries to adapt their economic models to new challenges, which in turn makes it necessary to analyse the economic feasibility of integrating alternative energy technologies. The introduction of RES into the production processes of the agro-industrial complex will optimise energy costs and help to increase the competitiveness of enterprises at the international level, while ensuring their energy autonomy and reducing negative environmental impact. In this context, a study of the economic aspects of renewable energy use in the agricultural sector is necessary to formulate strategic decisions that will promote the development of the industry, attract investment and implement state support mechanisms aimed at strengthening the country's energy security.

Scientific studies show that the introduction of RES in the agricultural sector is not only economically beneficial, but also strategically necessary to increase energy autonomy and reduce negative environmental impact. In the work of A. Dankevych *et al.* (2023) substantiated the effectiveness of bioenergy technologies for cost optimisation in agriculture and emphasised that government support and expansion of investment potential are the determining factors in the development of this sector. The study demonstrates that the integration of biogas plants and the use of biomass as an alternative energy source can improve the energy efficiency of agricultural enterprises and reduce their dependence on imported energy. The prospects for the development of distributed generation in the agricultural sector were considered by S. Boiko *et al.* (2023), who noted that the integration of decentralised energy systems contributes to improving the energy security of enterprises and optimising their production costs. The authors emphasised that the use of small solar and wind power plants reduces the load on centralised power grids and ensures stable energy supply even in remote regions, which is important for agricultural enterprises facing the problems of unstable energy supply and high electricity tariffs.

A separate aspect of the introduction of renewable energy in the agricultural sector was considered in paper V. Havrysh *et al.* (2022), who investigated the prospects of using sorghum as a feedstock for bioenergy production. The authors pointed out that this crop has a high energy potential and is able to provide biofuel production with minimal agricultural technology costs, which makes it attractive for farms in the southern regions of Ukraine.

The issue of integrating environmental, social and governance standards into the activities of agri-food enterprises was addressed in the work of T. Voronko-Nevidnycha *et al.* (2023). They emphasised that compliance with ESG principles (environmental, social and corporate governance) in the functioning of the agricultural sector helps to attract investment and increase the capitalisation of companies. The importance of regional peculiarities in the implementation of renewable energy was considered by M. Averkyna (2023). She analysed the sustainable development of the Polissya economic region from the perspective of environmental modernisation and energy transformation and stressed that a differentiated approach to the implementation of RES allows taking into account the specifics of each region and creating adaptive models of energy development. In the study, she substantiated the need to expand government support for farmers seeking to invest in RES, in particular through a system of tax incentives and grant programmes.

The scientific work of K. Anshu *et al.* (2023) clearly demonstrated that the successful integration of innovative energy technologies into various industries, including the agricultural sector, requires not only financial support but also the formation of a balanced public policy, including regulatory frameworks and incentives to attract investment in modern technologies. The authors emphasise that sustainable energy development is possible only if regional specifics and the needs of individual farms are taken into account, as well as active cooperation between the state and private initiatives. The authors also emphasise that only a harmonious combination of state regulation and private entrepreneurship can ensure the effectiveness of such initiatives. A study by F.J. Miranda *et al.* (2023) analysed in detail the importance of integrating solar energy into the functioning of the agro-industrial complex. The researchers emphasised that the introduction of these technologies contributes to a significant reduction in the costs associated with the use of energy resources, while ensuring a more environmentally friendly nature of production processes. In addition, the authors drew attention to the dependence of the effectiveness of such investments on the existence of state subsidies, as well as the importance of creating a transparent and clear regulatory environment that would regulate activities in the field of renewable energy.

The economic feasibility of using RES in the agricultural sector has been thoroughly explored in the works of researchers, but a number of aspects have remained outside the scope of comprehensive analysis, which highlights the need for further comprehensive research on this topic. The aim of this study was to assess the economic aspects of the use of RES in the agricultural sector of Ukraine and

to identify the main challenges and prospects in this area. The objectives of the study were to analyse the current state of implementation of RES in the agricultural sector of Ukraine, assess the economic feasibility of using certain types of RES and develop recommendations for optimising state policy in the field of stimulating investment in environmentally friendly technologies.

► Materials and methods

The study was based on an analysis of Ukraine's legal and regulatory framework, in particular the Law of Ukraine No. 555-IV (2003), which defines the legal and organisational framework for promoting the use of RES, including state support mechanisms, such as "green" tariffs, tax benefits and compensation programmes. The key element of the analysis was the Decree of the Cabinet of Ministers of Ukraine No. 1163-p (2024), which provides for a gradual increase in the share of RES in the energy balance of the agro-industrial complex, development of infrastructure for bioenergy generation and creation of conditions for the integration of the latest technologies into production processes. The study also examines the Decree of the Cabinet of Ministers of Ukraine No. 761-p (2024), which focuses on expanding the use of solar and wind energy in agriculture and identifies key measures to stimulate investment in renewable energy projects, including the provision of grants and low-interest loans.

The analysis of the economic benefits of implementing measures aimed at developing RES in the agricultural sector of Ukraine was carried out on the basis of statistical data published by the State Statistics Committee of Ukraine (n.d.) for the period 2018-2024. Financial investments in renewable energy projects, the dynamics of energy efficiency indicators, and changes in the use of these sources in the activities of agricultural enterprises were considered. In addition, the analysis involved information provided by the Ministry of Agrarian Policy and Food of Ukraine (2024), which includes detailed data on the distribution of state funding allocated to support the implementation of energy efficient technologies, as well as the results of an assessment of the economic benefits of such initiatives.

Statistical studies have revealed significant changes in the energy costs of agricultural enterprises, their impact on production costs and profitability. The data analysis also made it possible to assess the effectiveness of regulatory instruments aimed at stimulating the development of renewable energy, in particular, the relationship between the amount of public funding for such projects and energy efficiency in agriculture. Special economic research methods were used in the study. Statistical analysis (in particular, trend and comparative methods) was used to process data on the share of RES in the overall energy balance of agricultural enterprises, the dynamics of investment in the sector, and changes in energy costs. The empirical material was processed, including calculations, graphing and aggregation of indicators, using the Microsoft Excel spreadsheet processor, which ensured the results were clearly and accurately presented. The trend analysis tracked changes in key economic indicators (production cost, level of energy independence) in the period 2018-2024. Comparative analysis was used to compare the economic results of using traditional and RES. The economic and legal method

was used to study the regulatory framework governing the development of renewable energy in the agricultural sector. The content analysis method was also applied to study scientific sources and regulatory documents, which allowed for a comprehensive assessment of the economic prospects and challenges of introducing RES in the agricultural sector of Ukraine.

In addition, the study used a case study of a specific agricultural enterprise ("Agro-Kartel" LLC, Chernihiv region) to model the economic effect of switching to biomass as a heat source and estimate the payback period of investments. The choice of this enterprise was made due to its specialisation in greenhouse vegetable production, high energy intensity of production processes, and the availability of facilities that have already been partially adapted to the implementation of energy efficient technologies, while the location of the enterprise in a region with a developed agricultural raw material base for bioenergy and favourable logistical conditions for biomass supply ensured that the results obtained were representative of similar scenarios for average agricultural producers in Ukraine. To take into account spatial differentiation, elements of spatial analysis were applied, in particular, regarding the regional distribution of solar power plants and zonal climate features that affect the efficiency of RES. For the purpose of international comparison, a comparative analysis of macroeconomic effects and models of state policy in the field of RES was carried out on the example of Denmark, Germany, China and the United States. Additionally, the resource potential of biomass was assessed by sources of origin (straw, livestock waste, corn residues), volumes and potential for replacing natural gas. An environmental and economic assessment was also applied, which included an analysis of the impact on CO₂ emissions, the possibility of utilising agricultural waste and reducing the environmental burden on the environment.

To evaluate the economic feasibility of using biomass as an energy source in greenhouse farming, a comparative method of analysing operating costs for two alternatives was applied: the use of natural gas and the use of wood pellets. The calculation of heat demand was carried out using the formula (1):

$$Q = S \cdot q, \quad (1)$$

where Q – total heat demand for the heating season, kWh; S – greenhouse area, m²; q – average heat demand per 1 m², kWh/m².

The volume of natural gas required to cover this need was determined by the following formula (2):

$$V_{\text{gas}} = \frac{Q}{H_{\text{gas}} \cdot \eta_{\text{gas}}}, \quad (2)$$

where V_{gas} – volume of natural gas liquefied, m³; H_{gas} – lower calorific value of natural gas, kWh/m³; η_{gas} – thermal efficiency of the gas boiler, expressed as a fraction.

The cost of heating with natural gas was calculated using the formula (3):

$$C_{\text{gas}} = V_{\text{gas}} \cdot P_{\text{gas}}, \quad (3)$$

where C_{gas} – total gas heating costs, UAH; P_{gas} – price per 1 m³ of natural gas, UAH.

For the alternative variant with biomass, the amount of fuel required was calculated using the formula (4):

$$M_{\text{biomass}} = \frac{Q}{H_{\text{biomass}} \cdot \eta_{\text{biomass}}}, \quad (4)$$

where M_{biomass} – mass of wood pellets, kg; H_{biomass} – lower calorific value of pellets, kWh/kg; η_{biomass} – biomass boiler efficiency, in fractions of a unit.

The cost of biomass heating was determined by the formula (5):

$$C_{\text{biomass}} = M_{\text{biomass}} \cdot P_{\text{biomass}}, \quad (5)$$

where C_{biomass} – total biomass costs, UAH; P_{biomass} – price per 1 kg of pellets, UAH.

The fuel savings were calculated as the difference between the total costs of gas and biomass using the formula (6):

$$\Delta C = C_{\text{gas}} - C_{\text{biomass}}, \quad (6)$$

The payback period for the biomass boiler was estimated using the following formula (7):

$$T = \frac{I_{\text{add.}}}{\Delta C}, \quad (7)$$

where T – payback period, years; $I_{\text{add.}}$ – additional investment in the purchase of a biomass boiler, UAH.

► Results

The integration of RES is one of the important areas that determine the further development of Ukraine's agro-industrial complex, as the use of RES contributes to economic growth by increasing production efficiency, reducing production costs and reducing dependence on traditional energy resources. Sources such as biomass, biogas, solar, wind and hydropower can significantly reduce energy costs, which creates conditions for improving the competitive position of Ukrainian agricultural products on both domestic and international markets. In addition, an additional advantage is the positive impact on the environment, as the introduction of RES in production processes

helps to reduce greenhouse gas emissions, which is critical for global efforts to combat climate change (Mitov, 2024).

The role of renewable energy in the development of the agricultural sector goes beyond energy efficiency. It includes technological modernisation, rational use of resources, and the formation of sustainable models for the development of the sector. According to IRENA (2025) and the State Agency for Energy Efficiency and Energy Supply of Ukraine (2021), renewable energy should be considered a fundamental element of agricultural reform, combining economic and environmental goals into a single strategic development concept. The use of biogas plants on farms to process organic waste and generate energy has already been implemented in a number of agricultural enterprises in Vinnytsia and Poltava regions. Solar panels are used to provide energy for irrigation systems in the southern regions of Ukraine, in particular in Odesa and Kherson regions, where climatic conditions are conducive to maximising the use of solar energy. In addition, in Cherkasy region, there are farms that use combined RES models, combining solar energy with biogas plants to optimise energy consumption and increase the autonomy of production processes. The practice of using RES shows that RES are already becoming an integral part of the strategic development of Ukraine's agro-industrial complex, providing economic benefits, increasing competitiveness and minimising environmental impact (Usman *et al.*, 2024).

The use of RES is based on the principles of minimising energy dependence and rationalising resource consumption, which, in the face of current challenges, ensures the agricultural sector's high adaptability to global economic and environmental changes. The development of renewable technologies makes it possible not only to solve energy supply problems, but also to create additional economic incentives for attracting investment in agriculture (Ismanzhanov & Tashiev, 2016). Such processes contribute to the formation of a more diversified and sustainable agricultural production, which plays a significant role in ensuring the economic stability of the state. Types of RES in the agricultural sector are presented in Table 1.

Table 1. Types of RES in the agricultural sector

Type of RES	Feature	Examples of application in the agricultural sector
Solar energy	Using solar radiation to generate electricity or heat	Installation of solar panels to power farms, irrigation pumps, and greenhouse heating
Wind energy	Generating electricity using wind turbines	Providing energy to agricultural facilities such as warehouses or lighting systems
Bioenergy	Generating energy from biomass, biogas or biofuels produced by processing organic waste	Use of livestock waste to produce biogas, which is used for heating or powering equipment
Geothermal energy	Utilising the earth's heat for power generation or heating	Geothermal pumps for heating greenhouses or maintaining the temperature on farms
Hydropower	Generating electricity from small hydropower plants that use the movement of water	Use of mini-hydroelectric power plants to meet the energy needs of water farms or mills
Energy from waste	Generating energy by burning or processing agricultural and municipal waste	Use of straw, nut shells or crop residues as fuel to generate heat or electricity

Source: compiled by the authors based on V. Omelchenko (2022)

The use of solar panels is optimal in the southern regions, where the average sunshine hours per year are 2,000-2,200 (Ministry of Agrarian Policy and Food of Ukraine, 2024). However, the installation of such panels requires significant upfront investment, and their

performance depends on weather conditions. Bioenergy has a high potential due to the large volumes of agricultural waste, which allows for the production of biogas and biofuels while reducing the environmental burden, but the main drawback of this type of energy is the high cost

of infrastructure. Wind energy is feasible in steppe regions (Zaporizhzhia and Donetsk regions) where wind speeds exceed 5 m/s, but its deployment is limited by high costs and space requirements (Humeniuk & Humeniuk, 2023). Energy from waste is effective for heating households, but requires logistics and special equipment. Geothermal and hydropower have limited application due to specific geographical conditions.

A review of the practice of countries such as Denmark, China, Germany, and the United States shows that the achievement of higher economic results in the process of introducing renewable energy into the agricultural sector was made possible by the development of effective governmental regulatory mechanisms aimed at attracting investment in renewable energy. A special role in this was played by the creation of systems that ensure integration between the private sector and scientific institutions. In Germany, in particular, the Energiewende programme (Ethics Commission for Secure Energy Supply, 2011) was a key factor in modernising the energy infrastructure, aimed at a gradual transition to the use of RES, which in turn significantly reduced the dependence of the agricultural sector on fossil fuels, with the federal state of Bavaria seeing a 15% reduction in energy consumption in the agricultural sector between 2021 and 2024. In Lower Saxony, farms that switched to biogas plants reduced energy costs by 20%, which had a positive impact on their profitability (Qawaqzeh *et al.*, 2020).

The Danish experience shows that the implementation of a strategy of investing in the development of biogas plants focused on the needs of the agricultural sector has become a significant economic factor in reducing the costs associated with the disposal of agricultural waste and in ensuring stable access to energy resources for farmers. The effectiveness of this strategy was largely ensured by the introduction of government support programmes, which included a system of subsidies and tax breaks. In particular, in 2012, Denmark introduced a new subsidy scheme that provided fixed subsidies for biogas producers, which helped to increase biogas production for electricity and heat generation, as well as for processing into biomethane, which replaced natural gas. The scheme was valid for new applications until 2018, but the subsidies were granted for a 20-year period, so the bulk of biogas produced in Denmark today is still subsidised. Thanks to such programmes, the share of biomethane in the Danish gas system reached almost 40% in 2024, and by 2030, it is projected that gas consumption in the country will be 100% “green” (IRENA, 2025).

In China, the development of renewable energy in agricultural regions was manifested through the active introduction of solar panels and mini-hydroelectric power plants, which significantly increased the level of energy autonomy of agricultural enterprises. The introduction of RES has reduced farmers' electricity costs by an average of 30%, while productivity has increased by 15% due to stable energy supply. In addition, exports of organic products increased by 12% due to compliance with international environmental standards (Ramasubramanian *et al.*, 2021). Thus, the economic impact of this initiative is undeniable, as the use of RES in the agricultural sector has not only reduced energy costs, but also created the conditions for increased productivity and a more sustainable economic environment.

The practice of the countries under review shows that the integration of public investment, support for innovative technologies and incentives for agricultural businesses are fundamental prerequisites for the successful implementation of RES. In the context of Ukraine, such an integrated approach could become the basis for improving the energy efficiency of the agricultural sector, contributing to the sustainable economic development of the industry and reducing its dependence on fossil energy resources. This, in turn, will help to increase the competitiveness of Ukrainian farmers both in the domestic and international markets (Wang & Zhang, 2023).

Solar energy in Ukraine showed significant progress by 2022, reaching an installed capacity of 6.32 GW of solar power plants (SPPs), accounting for about 6% of the country's total generation (Humeniuk & Humeniuk, 2023). This was made possible by favourable natural conditions, the development of technical infrastructure, and government support, which created attractive conditions for investing in solar energy. However, agricultural enterprises faced a number of challenges in adopting solar technologies, mainly the high cost of equipment and limited access to finance, which made it difficult to integrate RES into the agricultural sector.

As of 24 April 2024, there were 1,369 solar power plants in operation in Ukraine, owned by 931 licensees, accounting for 75% of all renewable energy facilities. The largest number of SPPs is concentrated in six regions: Ivano-Frankivsk (142 plants), Dnipro (134), Vinnytsia (122), Khmelnytsky and Kyiv (107 each), and Mykolaiv (92). Instead, Luhansk and Donetsk regions have only 2 stations each, while Sumy region has 5 stations and Poltava region has 7 stations. Some of the solar power plants are located in the temporarily occupied territories of Kherson, Zaporizhzhia, Donetsk, and Luhansk regions, and they are currently not part of the Integrated Power System of Ukraine (Hubareva, 2023). The dynamics of launching new SPPs (according to licences) in 2018-2024 is shown in Figure 1.

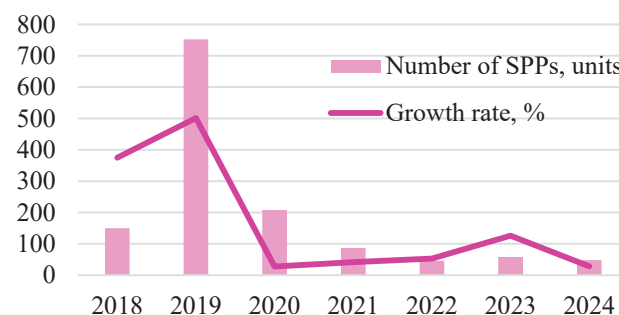


Figure 1. Dynamics of launching new SPPs (according to licences) in 2018-2024

Source: compiled by the authors based on L. Belozerova (2024)

The most active development of solar energy in Ukraine took place in 2019, when the largest number of new plants were commissioned. However, in the following years, the pace of construction slowed down, and after the outbreak of a full-scale war in 2022, licences for new SPPs stopped being issued in Kherson, Zaporizhzhia, Mykolaiv, Kharkiv, Donetsk and Luhansk regions due to hostilities

and occupation. By 2020, solar energy was a leader among European countries in terms of installed capacity growth, which demonstrates the significant interest of international investors in this sector. In 2020, approximately USD 1.4 billion was invested in the development of Ukrainian solar energy, and leading companies such as Jinko Solar, Trina Solar, ABB, and SMA Solar Technology were active in the market. The successful implementation of green auction projects, which are being implemented to reduce the cost of electricity and increase competition between investors, confirms the economic efficiency of this approach. For example, in 2019, during the first “green” auction, a quota for the construction of solar power plants with a total capacity of 78 MW was allocated at an average price of 5.5 euro cents per kWh, which was a significant step towards stabilising the industry (Hubareva, 2023). In the agricultural sector, solar panels are used to power irrigation systems, heat greenhouses, and power agricultural equipment, which helps to increase the energy independence of farms and reduce electricity costs. The dynamics of the installed capacity of solar power plants in Ukraine is shown in Figure 2.

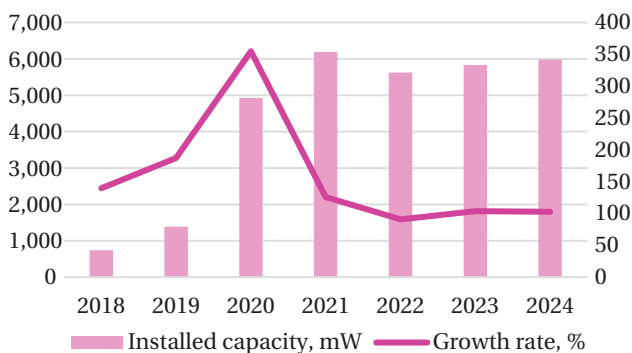


Figure 2. Dynamics of installed capacity of solar power plants in Ukraine, MW

Source: compiled by the authors based on L. Belozeroва (2024)

During 2019–2020, the installed capacity of solar power plants in Ukraine increased, with record volumes of SPPs commissioned (up to 6,194 MW in 2021). Starting in 2022, the war caused a decline in installed capacity to 5,623 MW, but the industry gradually recovered (5,983 MW in 2024), indicating that the sector is adapting to new conditions. The active implementation of solar energy contributes to the development of regions, especially rural areas, which is achieved through the creation of new jobs in the construction and operation of solar power plants, which in turn not only reduces unemployment but also stimulates economic activity in remote areas of the country. The use of solar energy also reduces greenhouse gas emissions, with each megawatt of installed solar capacity reducing CO₂ emissions by 1,500–2,000 tonnes annually, which has a positive impact on the environment and contributes to Ukraine’s international climate commitments (Mathew *et al.*, 2024). Thus, the development of solar energy is a promising area of energy policy and a significant contribution to the sustainable development of the economy and society. The installed capacity of RES facilities operating under the “green” tariff is shown in Figure 3.

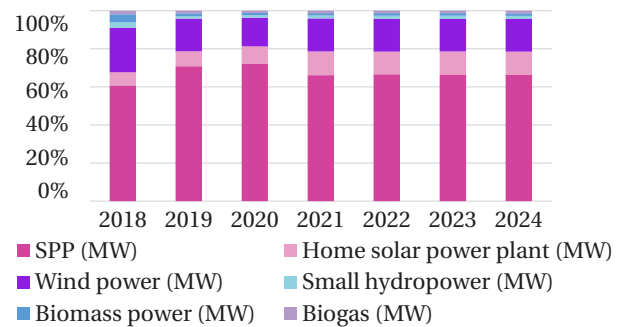


Figure 3. Installed capacity of RES operating under the “green” tariff, MW
Source: compiled by the authors based on L. Belozeroва (2024)

As of the end of 2021, the installed capacity of RES in Ukraine was 9,655.9 MW, including solar installations that covered the needs of private households (SPH), or 8,450.8 MW excluding SPH. The largest increase was observed in solar and wind energy, but since the beginning of 2022, the development of these sectors has slowed down, especially in 2022. At the same time, the home solar power plant segment continues to grow as households look for energy-independent solutions. Despite the challenging environment, biogas, bioenergy and micro-hydropower generation are also seeing gradual growth, indicating that the market is adapting to the crisis. From an economic point of view, the use of decentralised solar power plants in the agricultural sector helps to reduce energy costs, which allows farmers and businesses to increase their competitiveness, ensure energy independence and reduce the vulnerability of production to energy market fluctuations. In addition, such innovative solutions help to optimise energy consumption, which is of particular importance for export-oriented agricultural enterprises.

The military aggression of the Russian Federation against Ukraine has caused widespread damage to the country’s energy infrastructure, which has had a negative impact on the development of renewable energy (Semenenko *et al.*, 2024). Significant damage to the renewable energy infrastructure caused by the hostilities, including the destruction of substations, grid systems, loss of equipment, and the inability to access power plants in the occupied territories, has significantly affected the industry. For example, as of the end of 2024, about 70% of wind farms and 45–50% of solar power plants were decommissioned, which led to a more than twofold drop in electricity production from alternative sources (Ministry of Agrarian Policy and Food of Ukraine, 2024). Most of these facilities are located in the south of the country, where natural conditions favour the use of solar energy, and the calculation of total losses will only be possible after the de-occupation of these territories is complete.

The introduction of RES in the agricultural sector requires systemic changes at the level of modernisation of power grids to ensure the integration of new capacities, as well as improvement of legislation that would stimulate domestic production of equipment for solar power plants (Andreitsev *et al.*, 2024). Particular attention should be paid to the use of land unsuitable for agricultural use, such

as the territories in the exclusion zone of the Chernobyl nuclear power plant (NPP), where the pilot project “Solar Chernobyl” (n.d.) has already been implemented, which generates electricity using areas unsuitable for agricultural use. In addition, initiatives are being implemented to create wind and bioenergy capacities on degraded lands, which will reduce the dependence of the agricultural sector on traditional energy sources.

The national solar energy development policy should focus on attracting foreign investment, introducing innovative technologies and strengthening international cooperation, as the economic benefits of integrating RES into the agricultural sector can lead to increased productivity, improved energy efficiency and reduced production costs, which will open up new horizons for the sustainable development of this strategic sector of Ukraine's economy. The National Renewable Energy Action Plan until 2030 (Decree of the Cabinet of Ministers of Ukraine No. 761-p, 2024) outlines strategic goals and areas for the development of RES that should significantly change the structure of the country's energy sector, in particular by integrating modern environmental technologies. According to the plan, the share of RES in gross final energy consumption should reach 27% by 2030, which implies significant growth in three key sectors: in heating and cooling systems, the share should reach 33%, in electricity generation – 29%, and in the transport sector – 17%.

To achieve these goals, 38 large-scale measures are planned to be implemented, including investments in key areas of the industry's development. USD 12.6 billion is planned to be invested in electricity generation from RES, including USD 1.681 billion for the development of biomass and biogas generation facilities. In addition, USD 6.7 billion is earmarked for the reconstruction of heat supply systems, and the development of biofuels for the transport sector is estimated at USD 450 million for bioethanol production and USD 19 million for biodiesel. A special place in the structure of the National Plan is occupied by bioenergy, which is characterised by high potential for Ukraine due to its agricultural specialisation, favourable climatic conditions and access to significant amounts of biowaste. The use of biomass and biogas not only contributes to the country's energy independence, but also significantly reduces greenhouse gas emissions by converting organic waste into an energy source (Decree of the Cabinet of Ministers of Ukraine No. 1163-p, 2024; No. 761-p, 2024).

At the same time, the growth rate of electricity production from biomass and biogas remains relatively slow compared to other types of renewable energy. As of the beginning of 2024, the total installed capacity of electricity generation facilities using biomass and biogas reached 319 MW (excluding facilities in the temporarily occupied territories). During this period, 68 biogas plants with a total electrical capacity of 135 MW were operating in Ukraine, as well as 24 biomass power facilities with a total capacity of 178 MW, operating under the “green” tariff mechanism (Hubareva, 2023).

The development of bioenergy is one of the most promising areas for increasing the share of RES in total electricity production, especially in the context of the energy crisis and the need to reduce dependence on imported fossil fuels. As of early 2025, Ukraine has already implemented

a number of projects to convert thermal power plants (TPPs) and combined heat and power plants (CHPs) to use biomass, including at the Kamianets-Podilskyi CHP, which runs on wood chips, and at the Burshtyn TPP, which is testing the combustion of agro-pellets. The biomethane industry is also developing, and the first biomethane plants are already in operation, for example, at MHP Eco Energy, which produces biomethane from agricultural waste.

The integration of biomass and biomethane into highly manoeuvrable generating units, cogeneration systems or CHP plants, which are usually fuelled by natural gas, requires investments in equipment upgrades, new boilers and emission treatment systems. The cost of such a retrofit varies from EUR 5 million to EUR 20 million, depending on the capacity of the plant. Despite the high upfront costs, these changes can reduce natural gas consumption and dependence on imported fuel. According to the Bioenergy Association of Ukraine, bioenergy can account for up to 15% of the country's total energy balance, which is equivalent to replacing up to 3 billion m³ of gas per year, significantly strengthening the country's energy security (Belozerova, 2024).

According to the Bioenergy Policy Roadmap until 2050 and Action Plan until 2025 (2020), the main sources of bioenergy resources are agricultural residues, which account for 44% of the total, and energy crops, which account for 32% of this volume. Among agricultural residues, the largest share is occupied by grain straw (33%) and corn processing by-products (35%). Despite the significant potential of these resources, their energy use remains low: the potential of straw is used by less than 1%, and corn and sunflower residues are almost never involved in the bioenergy cycle. As a result, a significant amount of available fuel resources, estimated at USD 3-4 billion, remains untapped, which is a significant loss for a country with a high level of energy dependence. The structure of agricultural residues biomass potential is shown in Figure 4.

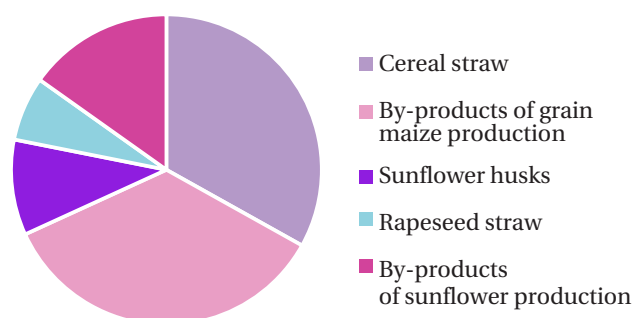


Figure 4. Structure of agricultural residues biomass potential, MW

Source: compiled by the authors based on L. Belozerova (2024)

In particular, straw and husks are efficient sources of thermal energy, and their combustion technologies in the form of fuel, wood or briquettes are already well established in practice. However, the weak infrastructure for collecting and processing such residues, as well as the lack of proper legislative incentives, are the main barriers to realising their energy potential. The efficient use of bio-waste, including

agricultural residues, is of strategic importance for achieving Ukraine's energy independence and reducing the cost of imported energy. The potential of bioenergy in Ukraine allows to replace up to 5 billion m³ of natural gas annually, which can reduce the cost of its imports by more than USD 2 billion. Integration of such resources into the bioenergy system will not only provide the country with additional energy, but also create new economic incentives for the agricultural sector. In particular, farms will be able to generate additional income from the sale of raw materials for biogas plants, and the development of local biowaste processing infrastructure will help reduce the cost of agricultural residues and increase the profitability of agricultural production.

The experience of other countries, such as the United States and European countries, demonstrates the significant potential and effectiveness of integrating bio-waste into the overall energy balance, which allows increasing the share of bioenergy in RES (Aliyev *et al.*, 2024). Given its agricultural resources, Ukraine has the opportunity to adapt successful approaches of other countries to its own conditions. However, the implementation of such initiatives requires large-scale infrastructure modernisation, attraction of foreign and domestic investments, proper state regulation, and close international cooperation (Islam *et al.*, 2024). The experience of integrating bio-waste in the US and European agriculture is shown in Table 2.

Table 2. Experience in integrating bio-waste in the US and European agriculture

Country	Share of bioenergy in total agricultural energy consumption as of the end of 2024	Main sources of biowaste	Economic effect	Government support
USA	12%	Livestock waste, corn residues	Reduce energy costs in the agricultural sector by USD 3 billion per year	Tax benefits, USDA grants for the development of biogas projects
Germany	18%	Farm waste, silage corn	900 biogas plants, 30% reduction in natural gas consumption in agriculture	Fixed tariffs for biogas, subsidies
Denmark	25%	Manure, straw, crop residues	Reduced CO ₂ emissions by 2.5 million tonnes per year	State financing of biogas cooperatives
France	10%	Winemaking waste, seed husks, animal residues	Save up to 20% on farm energy costs	Subsidies for the installation of biogas plants, low-interest loans

Source: compiled by the authors based on B. Crotman *et al.* (2024)

The general experience of these countries shows that successful integration of bio-waste into the agricultural sector helps to reduce energy costs, increase environmental efficiency and reduce dependence on fossil fuels. The use of bio-waste as an energy resource is characterised by significant economic viability, especially in the context of rising prices for traditional energy resources such as natural gas and coal. For example, 3 tonnes of corn cobs, which can provide the same amount of energy as 1,000 m³ of natural gas, cost about UAH 3,000. At the same time, in the European Union, the price for 1,000 m³ of gas is approximately EUR 1,000. In Ukraine, the equivalent energy value can be achieved for less than EUR 100, highlighting the significant cost difference. A similar cost-effectiveness is also observed in comparison with coal, where 2 tonnes of bio-waste correspond to 1 tonne of coal in terms of energy value, but cost approximately UAH 2,000, while a tonne

of coal is estimated to cost between UAH 10,000-15,000 (Yerniyazova *et al.*, 2024). The article presents the calculation of reducing the cost of growing vegetables on the example of using biomass as an alternative energy source for heating greenhouses in "Agro-Kartel" LLC (Chernihiv region). For a greenhouse farm with an area of 1 hectare (10,000 m²), with a seasonal heat demand of 150 kWh/m², the total heat demand was 1,500 kWh. If natural gas was used with an efficiency of 90% and a lower calorific value of 9.5 kWh/m³, the required fuel volume was about 175.4 thousand m³. At a price of UAH 8 per m³, heating costs during the season amounted to approximately UAH 1.4 million. When switching to wood pellets (boiler efficiency – 85%, calorific value – 4.8 kWh/kg), the annual fuel requirement was about 367.6 thousand kg. At a cost of UAH 3/kg, the total cost of biomass did not exceed UAH 1.1 million. A comparison of heating costs is presented in Table 3.

Table 3. Comparison of heating costs

Indicator	Natural gas	Biomass
Fuel demand	175,439 m ³	367,647 kg
Cost of fuel	UAH 1,403,512	UAH 1,102,941
Capital expenditure on equipment	UAH 200,000	UAH 500,000
Total costs (first year)	UAH 1,603,512	UAH 1,602,941
Total costs (subsequent years)	UAH 1,403,512	UAH 1,102,941
Annual fuel savings	–	UAH 300,571
Payback period	–	1 year

Source: compiled by the authors based on L. Belozerova (2024)

Thus, switching to biomass for heating a 1-hectare greenhouse in Chernihiv region can reduce annual fuel costs by UAH 300,571. The additional investment in equipment pays for itself in about one year. After that, the company receives net savings on fuel, which helps to reduce the cost of its products and increase its competitiveness in the market. Ukraine has a significant agricultural potential, which creates the preconditions for energy self-sufficiency through the large-scale use of biofuels. One of the promising areas that can contribute to solving the problem of energy supply at both the community and private household levels is the processing of agricultural residues, such as straw, into pellets. The creation and development of straw processing facilities can significantly reduce heating costs and solve the problem of energy supply in settlements without access to the gas supply system.

The introduction of RES in the Ukrainian agricultural industry is a key and promising area for creating conditions that will ensure the sustainable development of this sector, as evidenced by the results of numerous studies. In particular, an analysis of international experience shows that successful integration of RES into agriculture is possible through a combination of systemic state support, introduction of advanced technologies and active participation of the private sector. In this context, the achievements of developed economies that have managed to ensure a significant share of RES in the overall energy balance through effective investment attraction, research and innovation are illustrative (Nosratabadi *et al.*, 2019). Ukraine, with its considerable agricultural, land and natural potential, has all the prerequisites for the active development of renewable energy in the agricultural sector. Solar energy is developing particularly rapidly, as it is proving effective in reducing energy dependence and stimulating economic activity in rural areas.

The introduction of such initiatives helps to increase the level of energy autonomy of farms, reduces energy costs and stimulates the development of related industries.

Despite the significant challenges caused by military aggression, Ukraine retains opportunities to restore and modernise its energy sector, including the agricultural sector. The integration of RES into this sector will help reduce the environmental impact of traditional energy technologies, while opening up new prospects for job creation, local economic development and international competitiveness of agricultural products. Enhancing the country's energy security through the development of RES is one of the key aspects of the sustainable development strategy, which is particularly relevant in the context of rising global energy prices and the need to reduce greenhouse gas emissions. The prospects for the use of RES, in particular biogas, solar and wind energy, are directly linked to the development of international cooperation, available funding and the introduction of modern technologies into production.

Despite the significant potential of Ukraine's agricultural sector, the current state of energy modernisation in the industry is characterised by a number of challenges. The main barriers include insufficient funding for renewable energy projects, as well as a limited level of awareness among agricultural producers about the benefits of using renewable energy. Low access to credit resources and lack of adequate information support slow down the pace of adaptation of the agricultural sector to modern energy sustainability requirements. At the same time, the implementation of effective government policies aimed at stimulating investment and educational initiatives can significantly improve the situation, increasing the level of energy autonomy of farms and contributing to their profitability. Challenges and threats to the introduction of RES in the agricultural sector of Ukraine are presented in Table 4.

Table 4. Challenges, threats and ways to overcome barriers to the introduction of RES in the agricultural sector of Ukraine

Challenges	Threats	Recommended ways to overcome
Military operations and destruction of energy infrastructure	Destruction of energy networks, shortage of equipment, risk of investment loss	A state programme to rebuild power grids with grants and international assistance; compensation mechanisms for agricultural enterprises investing in renewable energy
Lack of financial resources in the agricultural sector	High initial investment, lack of affordable financing for small farms	Introduction of state preferential loans and subsidies for agricultural producers implementing RES; simplification of the tax burden for RES projects
Dependence on imported equipment	Logistical difficulties due to the war, currency risks, higher import prices	Establish a state programme to stimulate domestic production of solar panels and wind turbines; simplify customs clearance for imports of critical components
Shortage of personnel due to mobilisation and migration	Decrease in the number of specialists in the field of renewable energy, lack of skilled workers	Introduce educational programmes and grants for retraining agricultural sector workers in the field of renewable energy; attract foreign specialists and partnership programmes
Limited network infrastructure in rural areas	High cost of connecting SPPs to the grid, overloading of existing power lines	Create a mechanism of state co-financing for the construction of local power grids for agricultural enterprises
High risks of seasonality and instability of generation Competition for land resources	Instability of solar energy in winter, dependence on weather conditions The use of fertile land for solar power plants may reduce the area for growing crops	Introduce compensation mechanisms and stimulate the development of energy storage systems in the agricultural sector; support combined solutions (RES + biogas) Provide state guarantees for the use of degraded and unproductive land for RES; introduce tax benefits for companies that place SPPs on land unsuitable for agricultural activities
Problems with utilisation of used equipment	Lack of a system for recycling solar panels, environmental risks	Introduction of a national programme for the recycling of renewable energy components; obligation of producers to ensure waste recycling

Source: compiled by the authors based on V. Kovalenko (2024)

Despite the potential of renewable energy in the agricultural sector, there are a number of barriers that need to be addressed systematically. The hostilities have complicated the implementation of RES projects due to the destruction of infrastructure and the rising cost of equipment, which requires the active participation of the state and international partners in financing the restoration and modernisation of the energy system. Financial problems, lack of staff, and difficulties in accessing grid infrastructure have also become challenges that require the expansion of government support programmes, including concessional lending, subsidies for equipment purchases, and tax incentives for agricultural enterprises. Particular attention should be paid to legislative regulation of RES waste disposal and the development of local equipment production. The introduction of a national programme for the recycling of solar panels and batteries will help minimise environmental impact and create new jobs. Effective implementation of RES in the Ukrainian agricultural sector is only possible with a comprehensive approach that includes government support, attracting international investment and improving the legislative framework.

► Discussion

The economic potential for the introduction of RES in the agricultural sector identified in this study was consistent with the findings presented in A.Q. Al-Shetwi *et al.* (2024), which proved that the transition to 100% RES is possible if systemic barriers – technical, financial and regulatory – are removed. This study emphasised not only the importance of modernising the energy infrastructure in the agricultural sector, but also the need to create conditions for energy autonomy by reducing dependence on imported energy, an aspect that was particularly important in the context of energy vulnerability caused by military events.

Comparison of the results with the study by A. Dankevych *et al.* (2023) showed similar conclusions about the effectiveness of bioenergy technologies in reducing costs and improving energy efficiency in agricultural production. At the same time, the study focused on a comprehensive analysis of financial models for the implementation of biogas plants and biomass processing systems, taking into account the dynamics of production costs and access to state support. This made it possible to take into account the specifics of the Ukrainian context, in particular, the financing constraints for small agricultural producers. The importance of technological modernisation raised in R.R.C. Bastos *et al.* (2020) correlated with the analytical block of the study, which outlined the technological potential of agricultural waste processing for biofuel production. However, in contrast to the global focus of the aforementioned source, the present study focused on localised examples, taking into account the practical aspects of introducing new boilers, residue processing infrastructure and investment payback periods.

Financial instruments, in particular “green” bonds, were considered by L. Chang *et al.* (2023) as a means of mitigating the risks associated with the introduction of RES. The study reflected this problem through the prism of institutional support and its absence at the level of agricultural microbusiness: the lack of targeted government programmes capable of providing access to such instruments

for regional farms was noted. The results were also consistent with the findings of S. Boiko *et al.* (2023), who considered distributed generation as a means of increasing energy reliability in remote regions. The analysis of the Ukrainian agricultural sector confirmed that decentralisation of energy solutions, in particular through the installation of solar power plants in rural areas, does help reduce energy losses, especially in areas with unstable energy supply.

In the study by H. Tazvinga *et al.* (2020) highlighted the importance of taking into account local socio-economic and climatic conditions when adapting international RES experience. The study demonstrated the practical implementation of this thesis in the case of Ukraine: the expediency of placing RES infrastructure on degraded lands, in particular in the Chernobyl NPP area, as well as restrictions on wind energy in densely populated or difficult climatic zones, were substantiated. A summary of the study results in view of the position of R. Przygodzka *et al.* (2024) allowed confirming that state support in Ukraine is crucial, but unlike the Polish example, the Ukrainian model has not yet provided for the systematic integration of small farms into new energy formats due to the uneven distribution of resources and difficulty in accessing subsidies.

The effectiveness of investments in RES as a factor of economic growth in the agricultural sector was confirmed by the findings of E. Getachew *et al.* (2024), according to which a decrease in dependence on traditional energy sources is accompanied by an increase in energy efficiency. This conclusion coincided with the results of calculations of energy savings when using biomass in greenhouse heating presented in the study, which at a practical level demonstrated cost reduction and rapid return on investment. At the same time, not all studies confirm only the positive impact of RES, as E. Saitov (2020) drew attention to the difficulties associated with the development of wind energy in Central Asia and noted that high infrastructure costs and adaptation of technologies to local conditions are significant obstacles that may be relevant for Ukraine. D. Mignogna *et al.* (2024) emphasised the need for a cautious approach to the use of bioenergy, as although it has significant potential to reduce CO₂ emissions, overexploitation of biomass can lead to soil degradation, which is contrary to the principles of sustainable development.

Comparison of the results with the findings presented in existing studies shows that the development of RES in the agricultural sector has a number of common patterns that are manifested in different economic and institutional environments. According to the research of A.Q. Al-Shetwi *et al.* (2024), Poland, thanks to an effective government strategy and sound financial incentives, was able not only to reduce energy costs in the agricultural sector, but also to strengthen its economic sustainability. The same trend was observed in the results presented here, where the introduction of solar panels or biogas plants, subject to adequate financial and credit support, can significantly optimise the energy component of agricultural production costs and increase the competitiveness of farms in domestic and foreign markets, but Ukraine has not yet developed such a consistent and transparent system of regulatory measures that would ensure the rapid scaling of “green” technologies among small and medium-sized rural enterprises.

Comparison with the example of Kazakhstan presented in A. Abdikarimova *et al.* (2023) showed that in this country, the introduction of alternative energy in the agricultural sector faces insufficiently adapted regulatory mechanisms and a lack of clear political will. Similar problems, according to the study, remain relevant for Ukraine as well, as unregulated legislative procedures and limited access to investment for small farms make it difficult to introduce the latest solar or biogas technologies. This situation confirms the thesis that without government support and an optimised regulatory framework, even high-quality technical solutions cannot realise their full potential and influence the overall level of energy autonomy of the agricultural sector (Matviishyn & Harbarynina, 2023).

When analysing the cost-effectiveness of solar energy, it is worth noting that the results presented in this study (in particular, the calculations showing a reduction in the costs of heating and electricity for agricultural enterprises) are consistent with the findings of R.R.C. Bastos *et al.* (2020), who highlighted the significant economic potential of photovoltaic systems for farms. However, the limited access to modern high-performance equipment, especially in crisis regions where active hostilities are still ongoing, remains a significant obstacle. The study results confirmed that military aggression, which caused damage to energy infrastructure and the occupation of certain territories, made it difficult to implement solar power plants in the most favourable locations.

Regarding innovative solutions for small farms, the experience of combining biogas plants and solar panels described by L. Chang *et al.* (2023) logically correlates with the conclusion that it is advisable to decentralise the location of RES facilities and develop combined models. This approach truly ensures a higher level of energy autonomy; however, the implementation of such projects requires not only capital-intensive equipment but also appropriate mechanisms for state and international assistance to offset initial investment costs and promote the dissemination of these solutions at the local level. In this context, automation and intelligent power system management technologies are becoming critically important, as emphasised by D. Mignogna *et al.* (2024). The results obtained in this study fully confirm the high potential of digital optimisation of production processes to improve energy efficiency, but the likelihood of large-scale adoption of such solutions is still low due to significant financial barriers, which are especially noticeable for the segment of small and medium-sized agricultural enterprises.

In general, a comparison of Ukrainian experience with the work of foreign authors leads to the conclusion that strategic planning for the development of the agro-industrial complex, which integrates renewable energy, requires a synergy of economic, environmental and social factors. As summarised by A. Kaya & D.B. Budak (2023) conclude that only close cooperation between the research sector, government institutions and private investors contributes to the full deployment of bioenergy technologies, which is confirmed by the assessment of the prospects for RES development in Ukraine: with proper government regulation, reasonable modernisation of energy grids and available financial resources, farms are able to significantly reduce their dependence on fossil fuels, while improving

their economic performance and environmental responsibility. Thus, the results of the discussion show that although the development of RES has significant potential, a variety of aspects need to be taken into account to maintain energy independence in the agricultural sector. To achieve optimal results, it is necessary to ensure a comprehensive approach that includes government support, investment, training and innovation.

► Conclusions

A comprehensive analysis of the economic factors that accompany the integration of RES into the agricultural sector has shown that there are significant opportunities for consolidating financial, production and intellectual resources that can become the basis for sustainable growth of the domestic agricultural sector. The examples of solar, wind, and bioenergy use discussed above confirm that diversification of energy sources, combined with the rational use of agricultural residues and biomass potential, can minimise the energy dependence of farms, reduce energy costs by 20-30%, and increase profitability by at least 15% due to lower production costs. At the same time, the systematic use of renewable energy requires multi-level innovations that include not only technological modernisation of equipment but also the development of favourable economic and legal mechanisms. The potential of renewable technologies in agriculture is driven by the existing raw material base: agricultural waste alone in Ukraine amounts to more than 100 million tonnes annually, which can replace up to 5 billion m³ of natural gas per year (about 15% of total annual consumption). The transformation of such waste into highly profitable fuel in the form of biogas or pellets not only reduces the costs associated with the purchase of traditional energy sources, but also improves the environmental performance of farms by reducing greenhouse gas emissions. Each megawatt of installed solar capacity reduces CO₂ emissions by 1,500-2,000 tonnes annually, which is important in meeting the country's climate commitments.

The use of RES in agricultural production processes has a number of key benefits: it increases the level of energy independence, improves the financial stability of agricultural enterprises, opens up opportunities for developing new markets, and creates the preconditions for increasing Ukraine's scientific and technological attractiveness in global value chains. At the same time, the economic efficiency of such projects directly depends on the relevant government policy, which should include both financial and credit instruments (grants, soft loans) and legislative norms that encourage the localisation of energy equipment production, acceleration of permitting procedures, and development of public-private partnerships. The prospective development of the energy potential of the agricultural sector in Ukraine requires expanded compensation programmes, improved green auctions and support for long-term lending, which is especially important in the context of the post-war restoration of energy and logistics infrastructure, with coordination between different sectoral agencies interested in developing a comprehensive strategy that reconciles economic priorities with environmental safety playing a crucial role. The limitation of this study is its focus exclusively on the main areas of renewable energy implementation in the agricultural

sector, without taking into account demographic, socio-cultural factors and the role of digital technologies.

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Економічні аспекти впровадження відновлюваних джерел енергії в агропромисловому комплексі

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► **Анотація.** Метою дослідження було виявлення економічних викликів впровадження відновлюваних джерел енергії в агропромисловому комплексі України та обґрунтування шляхів їх подолання з урахуванням сучасних трансформацій. Методологічну основу становили методи статистичного аналізу (зокрема, трендового й порівняльного), економіко-правовий аналіз, а також контент-аналіз наукових джерел і нормативно-правових документів. У процесі дослідження було проаналізовано сучасні тенденції розвитку сонячної, вітрової та біоенергетики в аграрному секторі. Встановлено, що найбільший економічний ефект забезпечують проєкти, засновані на використанні біомаси, біогазу та сонячної енергії, які дозволяють досягти зниження витрат на енергозабезпечення до 20-25 % у середньому. Виявлено, що найбільші перспективи має біоенергетика завдяки значному обсягу доступної аграрної сировини; обґрунтовано, що щорічний потенціал заміщення імпортного газу біопаливом становить до 5 млрд кубометрів, що еквівалентно зменшенню витрат на понад 2 млрд доларів США. Проаналізовано динаміку впровадження сонячної енергетики в аграрному секторі за період 2018-2024 років, зокрема встановлено, що в умовах збройного конфлікту відбулося зниження частки працюючих сонячних електростанцій до 50-60 % через пошкодження інфраструктури, однак у західних і центральних регіонах зберігається тенденція до зростання встановлених потужностей. Виявлено, що ефективність впровадження відновлювальних джерел енергії залежить від рівня державної підтримки, наявності цільових інструментів, таких як «зелені» тарифи, кредити з низькою відсотковою ставкою, а також прозорих регуляторних механізмів. Практичне значення дослідження полягає у наданні рекомендацій для посилення підтримки впровадження відновлюваних джерел енергії, що сприятиме енергоефективності аграрного сектору, підвищенню прибутковості фермерських господарств та конкурентоспроможності їхньої продукції

► **Ключові слова:** інноваційні технології; сталий розвиток; конкурентоспроможність; екологічна стабільність; державна підтримка; інвестиційні стимули



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Theoretical and methodological aspects of the identification of agrarian reforms

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► **Abstract.** The relevance of the article lies in the absence of a systematic approach to identifying reforms in terms of their genuineness and success. Accordingly, the objective was to undertake a theoretical examination of the parameters shaping the conceptual framework of reforms and to provide a methodological justification for the indicators and criteria used in their identification. The research employed expert-analytical methods to examine the conceptual landscape of reforms, as well as their essence and content, based on the established indicators and criteria. The principal outcomes of the study include the formulation of parameters for determining the authenticity of reforms – distinguishing them, on the one hand, from revolutions and, on the other, from incremental improvements. As a result, the following indicators for identifying reforms were proposed: receptivity, scale, fundamentality, radicality, complexity, sociality, and effectiveness. The criteria for evaluating these indicators were substantiated using analytical data, comparative assessments across countries, expert evaluations, and factual analysis. The proposed theoretical and methodological framework was tested using case studies of agrarian reform in Ukraine, post-socialist states, post Soviet countries, China, and Japan. The practical significance of identifying reforms is highlighted, particularly in determining and characterising their genuineness and success through international and historical comparisons

► **Keywords:** reform; receptivity; scale; fundamentality; radicality; complexity; sociality; effectiveness

► Introduction

In recent decades, reforms have become a frequent feature of political and social agendas. The issue of reform is widely discussed across all segments of society. Those implementing reforms often overestimate their significance, even when such changes are merely marginal improvements. Consequently, alongside genuine reforms,

experts frequently encounter "quasi-reforms". A similar phenomenon occurs in international comparisons: leaders in certain countries portray their reforms as substantial while undervaluing those undertaken elsewhere. The same applies at the level of companies and corporations, where considerable subjectivity is involved. This situation

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largely stems from the absence of a methodology for objectively assessing the authenticity and effectiveness of reforms – an issue particularly pertinent to the agricultural sector. Therefore, the need to identify reforms based on their authenticity and success is both pressing and timely. This necessitates rigorous theoretical inquiry and the development of suitable methodologies.

The notion of reform has existed since the formation of states, social systems, and human institutions. A major turning point in the history of reform came with the transformational changes of the late 20th and early 21st centuries. The experience of these reforms has become the subject of substantial research and academic discussion. V. Zhuk *et al.* (2025) analyse contemporary models of land use and agricultural policy in Ukraine, comparing them with the experiences of other countries. Mechanisms for adapting to reform and opportunities for integrating European approaches are explored. S. Ibatullin *et al.* (2024) conduct an in-depth examination of the functioning of the land market following its liberalisation, including restrictions on ownership of up to 10,000 hectares, price trends, and the risks associated with land concentration. N. Zabolotna & E. Paliy (2024) explore the legal foundations of land reform, addressing legislative developments after market liberalisation and the legal risks that have emerged. B. Wilmsen *et al.* (2024) analyse recent reforms in rural China, particularly land rights reform and its impact on small farms. Their research demonstrates how large countries undertaking agrarian reforms maintain production and land balances. It highlights challenges similar to those faced by reforms in other countries – including deregulation, consolidation, and the preservation of small farms. B. Zia (2025) provides a tool for assessing the effectiveness of agricultural reforms and their resilience to global challenges, and emphasises that reforms concern not only land but also climate risks, international cooperation, and economic sustainability.

S. Demianenko (2024) analyses the initial phase of agrarian reform in Ukraine in the late 20th and early 21st centuries following the country's independence, concluding that agrarian transformations proceeded relatively slowly compared to those in Eastern European countries. One reason for this situation was the low efficiency of the state management of the reform process. In particular, this relates to land reform, which served as a key factor in all agrarian transformations. Only after the widespread implementation of land reform and the restructuring of collective agricultural enterprises in the early 2000s did a rapid increase in both the volume and efficiency of agricultural production begin. The long-standing moratorium on the sale and purchase of agricultural land – lasting over 30 years – was based on political rather than economic considerations.

Meanwhile, Yu. Lupenko (2018) provides a thorough and systematic examination of the evolution of management forms in Ukraine's agricultural sector, highlighting the critical transition from collective to private ownership and its significant impact on production structures and efficiency. The author critically assesses the main challenges facing agrarian reforms, including inadequate institutional support, limited access to financial resources, and persistent legal barriers that hinder the development of small and

medium-sized agricultural enterprises. Adopting a holistic, systemic approach, Yu. Lupenko *et al.* (2022) propose targeted strategies to overcome these challenges, such as legislative modernisation, the promotion of cooperative movements, the strengthening of institutional infrastructure, and the implementation of innovative management practices – all designed to enhance the sector's competitiveness and sustainability amid ongoing market transformations.

However, the vast majority of studies focus on describing the preconditions, organisation, technologies, and outcomes of land and agrarian reforms. At the same time, it has been observed that, as of 2025, the issue of identifying reforms according to specific standards remains inadequately addressed in academic research. As a result, not only politicians and government officials but also scholars often refer to minor improvements as reforms. However, such improvements cannot be equated with fundamental changes such as land privatisation or the replacement of state farms with privately owned enterprises. This underscores the relevance of the theoretical and methodological investigations into the identification of reforms, to which this article is dedicated. Based on an analysis of the conceptual environment surrounding the essence and content of reforms, this article aimed to formulate parameters for assessing the adequacy of interpretations of socio-political and economic changes as reforms and to justify the indicators and criteria for identifying the authenticity and success of reforms, using the agricultural sector as a case study.

► Materials and methods

In the course of the research, general scientific methods – including analysis and synthesis, induction and deduction, and analytical grouping – were employed, alongside specific methods such as abstraction, forecasting, and statistical analysis. The empirical basis of the study included the studies of O. Reyent *et al.* (2000) and V. Yurchyshyn (2001). In order to develop a system for identifying reforms in terms of their authenticity and success, it was necessary to determine relevant indicators for evaluating reform processes. Based on reform characteristics, the following indicators were formulated and applied in the research: 1) receptivity; 2) scale; 3) fundamentality; 4) radicality; 5) complexity; 6) sociality; 7) effectiveness. These indicators collectively reflect the key aspects of reform genuineness and success. Using these indicators and the corresponding criteria, a formalised assessment of reform authenticity and success was conducted.

In this context, the following criteria were applied. The first is the maximum statistically possible value for a given country. For instance, in assessing the extent of land privatisation, the total area of a country's land may serve as the benchmark. The second criterion is the highest value among a comparative group of countries. For example, the proportion of farmers involved in land privatisation in the country with the highest participation rate can be used. The third criterion involves expert assessments for indicators that cannot be quantified directly – such as reform complexity, radicality, and comprehensiveness – based on factual analysis.

To enable the identification of reforms and facilitate cross-country comparison, it was necessary to formalise evaluation according to these indicators and criteria.

For this purpose, a five-level scale and five-point rating system were applied: high – 5 points; above average – 4; average – 3; below average – 2; low – 1 point. This approach enables the quantitative calculation of comprehensive assessments of reforms in terms of their authenticity and success. The validity of the reform identification indicators formulated above was demonstrated using the example of agrarian reform in Ukraine. Based on the findings, a matrix of reform assessments was also developed.

► Results and discussion

A key foundation for the theoretical and methodological analysis of reform identification lies in understanding their conceptual environment. Thorough investigation of this environment enables the identification of essential parameters characterising reforms. The main principles are as follows: reforms are not revolutions that destroy not only the fundamental structures of society but also the material, spiritual, and legal values of citizens; rather, they are progressive transformations aimed at advancing civilisational development (Nesenenko, 2021). Reforms are not trivial improvements but fundamental changes that affect the core principles of social relations, are orientated towards social and democratic progress, and do not result in destabilisation, societal degradation, suppression of rights and freedoms, or deterioration of socio-economic conditions and political status (Baltserovych, 2000). Reforms are not inventions or whims of politicians, but rather essential measures designed to protect countries from revolutionary and socio-political upheaval, to enable the progressive transformation of social institutions, and to eliminate, in a timely manner, the obstacles hindering social development (Miklos & Kukhta, 2019; Yakushyk, 2019).

The validity of the reform identification indicators formulated above can be demonstrated using the example of agrarian reform in Ukraine.

1. Acceptability refers to a society's readiness and willingness to implement reform. This indicator reflects the reformability of the national context. On one hand, it denotes the maturity of society for reform; on the other, it reflects the complexity of the reform's implementation. High acceptability implies ease of implementation, whereas low acceptability signals high complexity. Therefore, the complexity indicator serves as an antonym to acceptability. The criterion in this case may be an expert assessment based on factual analysis.

In Ukraine during the 1990s, receptivity to agrarian reform was low, and, as a result, implementation was highly complex. This is evidenced by the failure to enact two parliamentary resolutions (Resolution of the Supreme Council of the Ukrainian SSR No. 10, 1990; Resolution of the Verkhovna Rada of Ukraine No. 25, 1992), despite the fact that neither resolution proposed radical reform measures. Subsequently, the reform process was compelled to proceed in three distinct phases: 1) small-scale privatisation of individual land plots; 2) large-scale privatisation of commercial agricultural lands; 3) comprehensive reorganisation of collective and state farms into private, marketorientated structures. The low level of public acceptance of agrarian reform in Ukraine stemmed primarily from socio-political factors. At the same time, the high complexity of its implementation elevated the importance of other reform indicators.

2. Scale refers to the extent of coverage – both in terms of the objects and subjects affected by the reform. The broader the absolute and relative number of entities impacted (e.g. through privatisation), the more extensive the reform. The criterion for this indicator may include statistical data, particularly the proportion of land and rural population affected by the reform.

In Ukraine, the small-scale privatisation of individual land plots (homesteads, gardens, summer cottages, garages, etc.) encompassed almost 9 million hectares of land and 19 million recipients across all 30,000 cities and villages in the country. The large-scale privatisation process concerned extensive land areas – approximately 28 million hectares – as well as a significant number of rural residents: 6.8 million individuals. It also included all agricultural enterprises, totalling 12,000. In total, the land reform affected around 38 million hectares of agricultural land, or approximately 85% of the national total, and involved 26 million recipients – about half of the adult population and nearly all rural inhabitants (Kyrylenko, 2008; Romanovska, 2017). Therefore, the Ukrainian agrarian reform was, in both absolute and relative terms, one of the most extensive.

3. Fundamentality refers to the depth of change and its impact on the foundational principles of the economy – namely, forms of ownership and the nature of business entities. If reform does not affect these foundations, it cannot be regarded as sufficiently fundamental. The criterion for this indicator may be the extent of agricultural land privatisation and the level of peasant participation in that process.

In Ukraine, land reform was entirely centred on altering the ownership structure: transitioning from state to private ownership. The full-scale privatisation of land was the clearest indicator of the reform's fundamentality. It also manifested in the transformation of management forms. All 12,000 state and collective farms were replaced with private farming structures. In their place emerged approximately 10,000 joint-stock and commercial companies, over 40,000 family farms, and around 5 million individual peasant farms, typically ranging from 0.25 to 2 hectares in size (Yakushyk, 2019).

4. Radicality refers to the determination and efficiency with which changes are implemented. The more swiftly and comprehensively reforms are introduced across time and space, the more radical the reform. The aim of radicality is to avoid procrastination and prevent a decline in reform effectiveness due to delays. The criterion for this indicator may include the reform's duration and the degree to which it is concentrated or extended over time and across regions.

In Ukraine, land reform unfolded in two main phases: the first involved small-scale privatisation; the second, large-scale privatisation. This sequencing was tactically sound, taking into account the acceptability of each phase. Successfully implementing the more socially acceptable small-scale privatisation significantly improved the receptivity to large-scale reform. The former, despite its scope, was executed largely within a three-year period (1992-1994). The latter, although highly politicised and extensive, was implemented over four years (1995-1999). While these timelines may not appear exceptionally short, they represent the best achievable outcomes under the prevailing conditions (Boiko & Teremets, 2013).

The economic reform was also delayed for nearly a decade. It was necessary to pass through an intermediate stage – from collective and state farms to private farms – via collective agricultural enterprises (CAEs). Only after the Decree issued by President L. Kuchma on 3 December 1999, this process was significantly accelerated. By the first half of 2000, the vast majority of collective and state farms had been transformed into private, market-orientated structures. By the end of that year, the reorganisation was virtually complete. This transition occurred without any organisational or economic losses; on the contrary, agricultural production in 2000 increased by 19% compared to 1999 (Boiko & Teremets, 2013).

5. Comprehensiveness refers to the inclusion of a complete and coordinated set of reform measures. Its aim is to ensure the effectiveness of reform by minimising the risk of disruption or failure. The criterion for this indicator may be based on expert assessment supported by factual analysis.

In Ukraine, comprehensiveness was primarily reflected in the integration of land and agrarian reform initiatives. Each reform area involved a distinct series of measures, implemented in a coherent sequence. In particular, the land reform comprised: 1) privatisation of individual land plots; 2) normative monetary valuation of agricultural land; 3) shareholding of commercial agricultural land; 4) privatisation of land shares; 5) introduction of land lease and other rights; 6) consolidation of land shares; 7) establishment of a land share market. These measures were implemented as a coordinated whole, albeit sequentially, and in line with technological and institutional capacities (Boiko & Teremets, 2013).

The agrarian reform included the following key components: 1) reorganisation of state and collective farms into collective agricultural enterprises (CAEs); 2) introduction of shareholding mechanisms for CAE property assets; 3) corporatisation of CAEs into private, market-orientated entities based on lease agreements for land and property shares; 4) development of an agricultural market; 5) cancellation of debts held by restructured farms and their financial rehabilitation; 6) implementation of incentive-based systems for taxation, credit provision, and investment (Sabluk, 2011).

6. Sociality refers to the extent to which reforms are directed towards the interests of rural populations. This criterion is essential for the political acceptability, success, and effectiveness of reforms. It may be assessed through indicators such as the share of rural residents engaged in the reform process, their participation in reform activities, and the outcomes they receive.

In Ukraine, the land and agrarian reform process demonstrated a high level of social orientation. Approximately 26 million individuals became landowners – representing more than half the adult population and nearly all rural residents. Nearly 7 million rural residents received land shares totalling 28 million hectares, with an average plot size of four hectares (Gaidutskyi, 2025). Furthermore, both small-scale and large-scale privatisations were carried out free of charge.

During the reform years, private-market principles were established to guide the social development of rural areas. Approximately 10 million rural residents became

landowners, each receiving plots exceeding one hectare. While the majority became landlords, many also pursued livelihoods as private entrepreneurs or farmers. Over a 15-year period, the total rental income received by land-owning farmers increased by a factor of 100, reaching 11.4 billion UAH. It is worth recalling that, in Europe, it was traditionally believed that a peasant who owned one morg (0.56 ha) of arable land could not be considered poor (Lupenko, 2018).

7. Effectiveness refers to the degree of measurable improvement in socio-economic indicators following reform, both in terms of agricultural sector performance and farmer well-being. The criterion for evaluating effectiveness may be derived from statistical indicators.

In Ukraine, reforms in the agricultural sector led to the cessation of economic decline and marked growth in production. Between 2000 and 2004, the average annual rate of agricultural output reached 6%, while the food industry grew by 16% annually. The proportion of barter transactions in agriculture decreased tenfold, lending expanded tenfold, and investment in fixed capital grew sixfold. In 1999, only 2% of agricultural production costs were covered by loans, whereas by 2004, this figure had risen to 32%. The financial condition of the sector also improved considerably: the transition from operating at a loss to profitability was achieved. The proportion of profitable enterprises increased fivefold, while the volume of taxes paid grew seventeenfold. Furthermore, state budget debt write-offs ceased, and foreign investment inflows into the sector increased (Lupenko, 2018).

Given the statistical evidence, facts, and arguments presented above, the majority of indicators related to Ukraine's agrarian reform merit high evaluation. A somewhat lower score may be assigned to the fundamentality of the reform, as Ukraine was neither able – nor, in practical terms, permitted – to carry out land restitution (i.e. the return of land to its former owners). A similar adjustment may apply to the radicality of the reform, due to its protracted implementation over a decade (1991–2000) and its division into three stages, which resulted from limited public receptivity and the overall complexity of the process.

Based on the methodology formulated and tested through the case of Ukraine's agrarian reform, similar analyses and evaluations should be conducted in other countries where significant reforms were implemented. In the post-socialist nations of Central and Eastern Europe (CEE), including the Baltic States, agrarian reforms demonstrated a number of distinct features. In these countries, the level of agricultural sector collectivisation was substantially lower, which led to broader public acceptance and smoother implementation of reforms. The complexity of reform implementation was relatively low, as political and socio-economic receptivity to reform was quite high. In most of these countries, rural residents eagerly anticipated land redistribution and the dissolution of state farms and cooperatives – developments that were generally supported by policymakers (Nesenenko, 2021).

The scale of reform in these countries was also limited, as small-scale private farming had already been relatively widespread prior to the transition from socialism – ranging from 30% in Hungary to 90% in Slovenia. In Poland, for example, under the socialist regime, only 10% of land

held by large landowners (latifundists) was nationalised, while approximately 75% remained under the control of small- and medium-sized farms. Across these countries, 20% to 40% of the land was transferred to rural residents, and several hundred state farms and cooperatives were dismantled. Following the reforms, the average share of privatised agricultural land reached 84%, approximately the same level as in Ukraine (85%) (Kadeniuk, 2018). However, in Ukraine, this figure was achieved entirely as a result of reform, whereas in the aforementioned countries, no more than one-third of the total was attributable to reform processes. Therefore, the fundamentality of reform in these countries may be assessed as below average. That said, given that these countries undertook land restitution (i.e. the return of land to former owners), the rating for fundamentality may reasonably be raised to an average level. Meanwhile, the radicality of the reform – reflected in the determination with which changes were implemented – may be assessed as above average.

At the same time, in these countries, market relations in agriculture, along with small-scale private landownership, were largely established even prior to the reform. This included a degree of economic freedom: the ability of rural residents to manage their property and products, set prices, purchase production inputs, access credit, and more. As such, the complexity of reform implementation was limited, and this indicator may be assessed at an average level. With regard to sociality, these countries already exhibited considerable diversification of land ownership before reform. For instance, 54% of the population were agricultural landowners, a figure comparable to Ukraine's. However, in Ukraine, this indicator was achieved almost entirely due to reform, whereas in these countries, only around a third of the outcome resulted from reform. Therefore, the sociality of reform in these countries may also be rated at an average level. A similar assessment may be applied to effectiveness. Between 2000 and 2004, the average annual growth in agricultural production in these countries was 1.9%, compared to 6% in Ukraine (Demianenko, 2024). Accordingly, the effectiveness of agrarian reform in these countries may also be rated at an average level. In the post-Soviet states – excluding Ukraine and the Baltic countries – agrarian reforms had their own specific features. However, in general, the complexity of reform implementation was somewhat lower than in Ukraine. Many of these countries were governed by administrative regimes capable of enforcing top-down reforms decisively, which arguably made the implementation process easier. Nevertheless, the decisive factor was the political will of national leaders and their awareness of the necessity for reforms – qualities that were often lacking (Lupenko *et al.*, 2022).

The scale of agrarian sector reform in these countries was also lower, for various reasons, than in Ukraine. In particular, the extent to which reform encompassed both the objects and subjects – especially regarding the completeness of agricultural land privatisation – was significantly more limited. For instance, in Russia, following the reform, only 39% of agricultural land was under private ownership, compared to 85% in Ukraine. In the CIS countries, the proportion was even lower, at 32%. In many of these states, rather than granting full ownership rights, intermediate forms of land tenure persisted for an extended

period, including “lifelong inherited ownership”, “lifelong use”, “short-term use”, and “land leasing from state and local authorities”. As a result, the fundamentality and radicality of reforms in these contexts can be rated at an average level. In the countries of Central Asia and the Caucasus, the state was unable to provide smallholder family farms with a comprehensive package of support measures to ensure reform comprehensiveness. In contrast to Ukraine, these countries lacked incentive-based preferential mechanisms for taxation, credit access, investment in modernisation, and other forms of institutional support. The social orientation of reform in these countries was also weaker than in Ukraine. For example, in Russia, only 38% of the population were agricultural landowners, compared to 57% in Ukraine, 54% in Central and Eastern European countries, and 26% across the CIS overall. In several countries, particularly Russia and Kazakhstan, land consolidation and the emergence of latifundia became widespread during the reform process, significantly undermining its social character. The same applies to the effectiveness of reforms, which proved to be markedly lower than in Ukraine. Between 2000 and 2004, the average annual growth rates of agricultural production were: Ukraine – 6%, Russia – 3.1%, Belarus – 4.4%, and Kazakhstan – 3.3% (Gaidutskyi, 2019). Consequently, the evaluation of reforms in these countries across the relevant indicators would be lower than in Ukraine.

The Chinese agrarian reform was among the most widely cited within the then socialist bloc. However, in practice, its scope was more limited. The main measures of reform included: decommunisation, the introduction of family-based tenancy contracts, the establishment of peasant and communal (“village-hair”) farms based on land leasing, partial liberalisation of product sales, input procurement and pricing, and restrictions on the state procurement system for agricultural products (Mochernyi, 2000). The acceptability of agrarian reform in China – particularly after the Maoist era, which was characterised by the extreme collectivisation of the peasantry – was relatively low. For these reasons, the complexity of implementing the reform considered be might initially high. However, given the early and deliberate narrowing of the reform's parameters (primarily to family contracting and leasing), the actual complexity within this limited framework was not substantial. Therefore, an average rating for complexity is appropriate. Meanwhile, the broad participation of both peasants and agricultural land in the reform justifies a high assessment of its scale.

This also resulted in lower scores across several indicators, particularly in relation to fundamentality, radicality, and complexity. For instance, the Chinese agrarian reform did not involve a change in land ownership structure – state ownership was not replaced by private ownership. Only the management system of the commune was restructured, shifting to family-based farming units. Therefore, the fundamentality of the reform cannot be rated highly. Similarly, the low radicality of the reform – evident in its partial implementation and prolonged timeline – is clear. This also explains the relatively low complexity of the reform. Despite some liberalisation, the system of state contracting, price regulation, provision of inputs, and regulation of product sales remained largely

intact. Consequently, the trade, financial, and credit relations between the state and peasant farms were limited and far from fully market-orientated.

While legal access to land was extended to all peasants (approximately 800 million), and this encompassed most agricultural land, Chinese peasants were not granted full property rights. Instead, land was allocated on a leasehold basis, meaning peasants could neither own nor freely manage their plots, become landlords, nor receive rental income. However, the scale of participation – a uniquely massive mobilisation of the rural population – raises the rating of the sociality of the reform to above average. A similar conclusion applies to the assessment of effectiveness. Between 2000 and 2004, China's average annual growth in agricultural production was 3.7%, notably lower than Ukraine's 6% (Khodakivska & Mohilnyi, 2018; Nesenenko, 2021). Nonetheless, the transition from communal to family- and village-contracted farms produced significant improvements in agricultural output and overall sector performance. Therefore, the effectiveness of China's agrarian reform may be rated as above average.

The Japanese agrarian reform entailed the state purchase of land from large landowners (latifundists) – those holding more than 5 hectares – and its redistribution to peasants at a fixed, minimal price, with 30-year instalment plans. The keywords here – “purchase” and “sale” – highlight the distinctive character of this reform and its divergence from post-socialist transformational models. The individual land plots allocated to peasants were very small (0.5-1 ha), and the total landholding per farm was capped at 3 hectares, with the average amounting to only 1.8 hectares. As a result of the reform, both the number of peasant landowners and the total area under their ownership doubled. Concurrently, the government invested

heavily in rural infrastructure and provided extensive subsidies, grants, loans, and other support to small, newly established farms. Owing to this reform, agricultural output increased by 3% annually between 1955 and 1970. Despite only 13% of Japan's territory being suitable for agriculture, the country managed to produce 90% of its food needs by the 1970s. Several other nations – Taiwan, South Korea, Thailand, Indonesia, Malaysia, and Vietnam – pursued similar paths (Mochernyi, 2000).

Based on the methodology for assessing the indicators of reform identification, the characteristics in this case may vary. Indeed, the acceptability of the reform was high, as it was implemented under pressure from the occupation regime, particularly through the purchase of land from large landowners demoralised by the war. Therefore, the complexity of implementation can be assessed as below average. The coverage of land and the rural population reached approximately half of the total, so the scale of the reform may be rated above average. However, during the reform, the form of ownership remained unchanged – it was private both before and after – and only the subjects of ownership and management changed, on a purchased basis. As a result, the fundamentality of the reform may be considered below average. At the same time, the radicality of the reform and the scope of measures to support newly established farms merit high ratings. Furthermore, as the number of peasant landowners doubled, the sociality indicator may also be assessed as above average. The same applies to the effectiveness of the reform: although the average annual growth in agricultural production was 3%, which is half the rate recorded in Ukraine, the indicator still warrants an above average rating. Based on the research conducted, a matrix of agrarian reform assessments was developed (Table 1).

Table 1. Matrix of agrarian reform assessments

Indicators of identification	Ukraine	Post-socialist countries of CEE	Post-Soviet states	China	Japan
1. Receptivity	5	2	4	3	2
2. Scale	5	3	3	5	4
3. Fundamentality	4	3	4	3	2
4. Radicality	3	4	3	3	5
5. Complexity	5	3	3	3	5
6. Sociality	5	3	3	4	4
7. Effectiveness	5	3	4	4	4
Total	32	21	24	25	26

Notes: data are averaged across country groups

Source: authors' compilation

Based on the qualitative characteristics and the formalised assessment, the composite score for the agrarian reform in Ukraine was the highest. This has also been affirmed by numerous scholars, including A. Aslund (2015) and I. Miklos & P. Kukhta (2019). Notably, among contemporary scholars, serious critical remarks concerning the Ukrainian agrarian reform are virtually absent. Some researchers underscore the importance of implementing reforms not as superficial formalities, but as deep, systemic transformations that affect the core structures of socio-economic relations and reflect a social-democratic orientation. They emphasise that the success of reforms

is contingent upon their social acceptability, the scale and depth of change, and the speed and consistency of implementation (Kyrilenko, 2008). This viewpoint resonates with the findings of other scholars, such as D. North (1990), who underscores the importance of institutional change as a driver of sustainable development, and D. Rodrik (2007), who highlights that the legitimacy and inclusiveness of reforms are crucial for long-term success.

Moreover, O. Khodakivska & O. Mohilnyi (2018) and V. Yakushyk (2019) emphasise the necessity of considering the purposeful nature of reform processes during evaluation and identification, which helps to minimise the

influence of random political impulses. This aligns with insights from M. Grindle (2004), who argues that political will and strategic leadership are critical for steering reforms away from short-term political fluctuations and ensuring their continuity. Special attention must be paid to balancing the gradual implementation of changes with their effectiveness, in order to prevent social destabilisation and ensure sustainable economic development. This perspective fully aligns with the author's proposed approaches. At the same time, it remains crucial that reforms do not result in destabilisation or the deterioration of the socio-economic situation, echoing the warnings of W. Easterly (2001) about the risks of reform failures leading to economic setbacks and social discontent.

In light of the above, the success of reforms in Ukraine's agrarian sector depends not only on the internal consistency of changes but also on external conditions and the development potential of the industry. Therefore, when considering the future prospects of the agricultural sector, it is important to take into account natural resources, market conditions, and the socio-economic challenges facing the country's agriculture. Ukraine, which benefits from favourable natural conditions for agricultural development and has already established the foundations of a market economy, holds significant potential for successful growth. However, it is impossible to ignore the ongoing challenges facing the sector. Even its current record performance indicators do not fully reflect the industry's existing potential, particularly when compared to those of Western European countries. The priority areas for sectoral development include overcoming the consequences of war and economic crisis, ensuring financial recovery, accelerating economic growth, and promoting innovation and social progress. It is essential to strengthen the social infrastructure in rural areas – including housing, education, healthcare, culture, and sport – by addressing key issues such as transport connectivity and employment opportunities for the rural population. This is supported by both post-war European experience and Ukrainian regional practice. A key issue is increasing wages for rural workers, as farmers and entrepreneurs in the countryside also face a shortage of labour, which in turn slows the development of their enterprises.

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► Conclusions

The study of the conceptual environment of reforms has outlined the parameters of their definition and characteristics, substantiating that reforms are neither revolutions that dismantle fundamental socio-political systems nor minor improvements. Reforms represent a set of fundamental and farreaching changes characterised by scale, fundamentality, radicality, complexity, sociality, and efficiency. Based on an analysis of extensive international reform practices, a set of indicators for their identification and evaluation has been formulated. These include: 1) receptivity; 2) scale; 3) fundamentality; 4) radicality; 5) complexity; 6) sociality; 7) efficiency. These indicators comprehensively capture the principal dimensions of reform characteristics. On this basis, a methodology for the formal assessment and cross-national comparison of reforms has been proposed. The validity of these indicators and the criteria for calculating evaluations have been demonstrated using the example of Ukraine's agrarian reform. According to both qualitative assessments and the formal evaluation framework, the overall indicator of the authenticity and success of Ukraine's agrarian reform was the highest among post-socialist, post-Soviet and other studied countries. A new phase of agrarian reform began with the opening of the land market in 2021, allowing the purchase and sale of land by individuals and, in the future, by legal entities and foreign investors. This opens up new prospects for scientific and applied research. It is essential to investigate the impact of the land market's liberalisation on land value, agricultural productivity in both crop and livestock sectors, business profitability, investment in research and development, and the optimisation of business processes.

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Теоретико-методологічні аспекти ідентифікації аграрних реформ

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► **Анотація.** Актуальність статті зумовлена відсутністю системи ідентифікації реформ на предмет їх справжності та успішності. Тому метою стало теоретичне дослідження параметрів понятійного середовища реформ та методологічне обґрунтування показників і критеріїв їх ідентифікації. В процесі дослідження використані експертно-аналітичні методи вивчення понятійного середовища реформ, їх суті і змісту за сформульованими показниками та критеріями. Основними результатами дослідження є сформульовані параметри визначення справжності реформ, які, з одного боку, відрізняють їх від революцій, а з другого – від дріб'язкових удосконалень. В результаті дослідження сформульовано показники ідентифікації реформ: сприйнятність; масштабність; фундаментальність; радикальність; комплексність; соціальність; ефективність. Обґрунтовано критерії оцінки показників на основі аналітичних даних, порівняльних оцінок окремих країн, експертних оцінок та аналізу фактів. Здійснено апробацію відповідних методологічних та методичних розробок на прикладі аграрної реформи в Україні, постсоціалістичних країнах, пострадянських країнах, Китаї та Японії. Розкрито практичне значення ідентифікації реформ насамперед для визначення і характеристики їх справжності та успішності, в тому числі на основі порівняння між країнами та різними історичними епохами

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

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