Research Article

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LOGISTICS INNOVATION MECHANISMS OF AGRICULTURAL COMPETITIVENESS DEVELOPMENT IN SPATIAL ECONOMIC TRANSFORMATION

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Background. The study examines the transformation of the logistics component of enterprises' competitiveness in the agricultural sector of Ukraine under conditions of spatial economic changes driven by military events and the restructuring of export infrastructure. The relevance of analysing export logistics channels stems from their decisive role in the resilience of agricultural production given changes in transport route configurations, increased risks, and the need to adapt to new geo-economic conditions.

Purpose. This study aims to analyse the impact of the structure and diversification of export logistics channels on the competitiveness of the agricultural sector and develop an integrated approach to measure the logistics component of comprehensive performance.

Findings. The study employs statistical, comparative analysis methods, and an index approach to assess the structure of logistics flows. The dynamics of agricultural production indices for 2014–2024, the structure of export logistic flows, and the share of transport modes in agricultural exports are also considered. The diversification index of logistics channels was calculated, reflecting the transition from a highly concentrated logistics structure to a more diversified one. A Logistics Competitiveness Index was also constructed, which integrates export volume, degree of diversification, and the share of alternative routes. The results demonstrated a transition from a mono-channel maritime model in 2021 to a diversified configuration in 2022–2023, which performed an adaptive function and contributed to the recovery of export activity. In 2024, the export volume increased to 70 million tonnes, 12.9% more than in 2023 (62 million tonnes). However, this occurred against the background of a partial return to a more concentrated structure of logistics flows, driven by the restoration of the maritime transport channel's role.

Implications. The competitiveness of agricultural enterprises in a transformed economic space is determined not only by the scale of exports but also by the structural balance of transport channels. Maintaining a multichannel logistics model is considered a key element of logistics innovation mechanisms to ensure resilience and long-term competitive advantage.

Keywords: Agricultural Enterprises, Competitiveness, Diversification, Innovations, Logistics.

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1. Introduction.

The agricultural sector is a key driver of recovery and spatial restructuring of the economic space. Military actions, destruction of transport and port infrastructure, changes in the configuration of foreign trade corridors, relocation of production facilities, and movement of labour resources have led to a profound transformation of the spatial organisation of agricultural production and sales markets (Purdenko et al., 2023). Under such conditions, the competitiveness of agricultural enterprises is increasingly determined not only by resource potential or the technological level of production but also by the efficiency of logistical support for export flows.

Changes in the structure of transport routes and the reorientation of channels for product movement have strengthened the dependence of agricultural production effectiveness on logistical factors, as reflected in transportation costs, delivery speed, and reliability of access to external markets. This underscores the need to develop logistics innovation mechanisms to enhance the competitiveness of agricultural enterprises, combining value chain management, diversification of transport channels, and the use of digital tools to coordinate flows within the transformed economy.

Simultaneously, the scientific problem lies in the underdeveloped methodological approaches to assessing the influence of the structure of export logistics channels on the competitiveness of agricultural enterprises in the context of the spatial transformation of the economy. This requires deepening the theoretical substantiation and developing tools to quantitatively assess the role of logistics diversification in ensuring the resilience and efficiency of export activities in the agricultural sector.

This study aims to develop a comprehensive framework for assessing logistics innovation mechanisms that enhance the competitiveness of agricultural enterprises amid spatial economic transformation and quantitatively determine the influence of the structure and diversification of export logistics channels on the resilience and effectiveness of export activity.

The proposed approach combines the assessment of export volumes, the degree of diversification of transport channels, and the share of alternative routes into an integral logistics competitiveness index, enabling a quantitative reflection of the relationship between the structure of logistics flows and the competitive position of agricultural enterprises.

2. Literature Review.

2.1. Theoretical Approaches of Agricultural Competitiveness.

The literature on agricultural competitiveness has largely relegated logistics to a factor rather than the core of development mechanisms. Approaches to interpreting the competitiveness of agricultural enterprises focus on the combination of production-resource potential, organisational-economic management mechanisms, and the market environment, which form the foundational framework of sectoral efficiency (Kravchenko et al., 2024; Sabluk, 2021). The conception of such approaches is presented, in particular, in the studies of Countryman et al. (2024), where the competitiveness of agricultural enterprises is associated with adaptability to the market environment, the use of comparative advantages, and integration into international agri-food value chains, while the modernisation of production and logistics infrastructure is defined as a key direction for strengthening positions in global markets.

A separate direction is formed by studies on the competitiveness of agricultural products in foreign markets, in which a shift of emphasis towards institutional, infrastructural, and risk factors can be observed. Kvasha et al. (2024) examined competitiveness through the prism of the export positions of Ukrainian agricultural products, the impact of the full-scale war on logistics routes and access to external markets, and an analysis of Ukraine’s strengths and weaknesses as an agricultural exporter. It was emphasised that the loss of part of the port infrastructure, the increase in logistics costs, and uncertainty regarding “security corridors” for exports effectively reduce realised competitiveness, even when high product quality is maintained.

In this context, logistics emerges not as a secondary factor but as a system-forming factor that determines enterprises' ability to convert potential into real market results (Bojnec & Fertő, 2009; Hobbs, 2020; Török et al., 2013).

Studies on the essence and factors of agricultural enterprise competitiveness detail the structure of these factors and bring them closer to the logistical issues (Semchuk et al., 2025). Thus, Wang et al. (2024) substantiated a multilevel system of factors for strengthening competitiveness, which, in addition to resource provision and product quality, includes infrastructural, spatial, and managerial components. Additionally, studies devoted to the influence of martial law on the state of competitiveness of agricultural enterprises, logistics disruptions, rising transport costs, restrictions on export infrastructure, and changes in the spatial configuration of demand are considered key threats requiring fundamentally new managerial decisions (Deininger et al., 2024; Goyal & Steinbach, 2023; Ketsetsidis & Pistikou, 2024).

2.2. Innovative Development and Logistics Mechanisms in the Agricultural Sector.

The theoretical framework, focused on the development of the agricultural sector, serves as the basis for the design of innovative logistics mechanisms. Mamchur and Studinska (2024) argue that the innovative development of the agricultural sector is associated with the formation of a national resilience system, in which innovations in production technologies, management, and logistics are considered guarantees of adaptation to shocks and the maintenance of food security.

Belova et al. (2025) analysed the impact of the European Union's Common Agricultural Policy on the innovative development of the agricultural sector and food security, emphasising the importance of integrating Ukrainian agricultural enterprises into European value chains and logistics platforms. Vlasenko et al. (2019) outline innovative approaches to managing economic transformation, emphasising the role of logistics solutions in ensuring the flexibility of business models and redistributing flows across space.

However, the focus of these studies extends beyond purely agricultural logistics and establishes a theoretical framework for combining the innovative, organisational, and spatial aspects of transformation.

At the intersection of innovation and logistics in the agricultural sector, several studies view logistics technologies as instruments of innovation for agro-industrial enterprises. Based on theoretical approaches and the practice of agricultural enterprises, scholars have considered logistics technologies as a strategic instrument for managing material, financial, and information flows, emphasising their role in increasing resilience to market risks and forming a new paradigm of digital, intelligent, and environmentally oriented agrologistics (Arimany-Serrat et al., 2024; Brockova et al., 2021; Nitsenko et al., 2025; Stanescu et al., 2025).

2.3. Infrastructural and Spatial Aspects of the Development of Agrologistics.

The development of agrologistics as a separate research direction is primarily focused on characterising the structure of logistics systems and diagnosing infrastructural problems in the agricultural market. Trushkina and Dzwigol (2024) outlined the theoretical and applied essence of agrologistics, determined its role within the agro-industrial complex of Ukraine, and defined the structure of the logistics system and key factors determining its effectiveness, including the quality of transport infrastructure, the level of development of storage capacities, and the organisation of distribution channels.

Moreover, the logistics component does not meet market needs: insufficient elevator capacities, the uneven territorial distribution of warehouse infrastructure, and bottlenecks in railway and port logistics directly translate into losses of competitive positions for Ukrainian products (Ekleme & Yercan, 2024; Kotenko et al., 2021; Naumov et al., 2025; Pavlenko et al., 2023). Studies on innovations in the logistics of agricultural product distribution emphasise the high cost of access to infrastructure.

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The inefficiency of logistics processes in Ukraine results in significant product value loss at the transportation and transhipment stages, directly limiting the competitiveness of producers. New emphases in agrologistics research focus on analysing the transport component of agri-food chains in Europe. Factors in the development of transport-logistics infrastructure of agri-food value chains have been identified, showing that the coordination of transport policy determines the efficiency of chains, the development of trade infrastructure, and the formation of new retail and electronic commerce formats (Balanovska et al., 2021; Naumov et al., 2025; Sfounis et al., 2024). Despite the detailed consideration of transport and market aspects, the level of elaboration of the micro-level mechanisms through which individual agricultural enterprises can integrate into these chains and redistribute logistics risks remains limited.

Studies focused on the industrial sector have contributed to understanding logistics innovation approaches to enterprise management. Cherchata et al. (2022) considers logistics innovation systems to be the basis for forming a non-industrial economic order, in which logistics serves as an integrating element between production and market processes, and innovation as a condition for realising the potential of this integration.

These approaches outline resource, organisational, institutional, and market determinants and emphasise the growing role of innovation and logistics as instruments of sustainable development. At the same time, most studies either focus on the macro-level (export positions, market infrastructure, and public policy) or are limited to the functional aspects of logistics, leaving aside an integrated analysis of innovation-logistics mechanisms at the enterprise level. Despite considerable scientific advances in agricultural enterprise competitiveness, innovation, and agrologistics, several conceptual and methodological uncertainties remain in contemporary research. The content and structure of innovation logistics mechanisms as a holistic management system integrating the production, infrastructural, digital, and spatial components of enterprise development remain insufficiently specified.

Innovation and logistics are considered fragmentarily, either as separate functional subsystems or as external factors influencing competitive positions, without revealing the internal architecture of their combination at the enterprise level (Masi et al., 2024). The methodological toolkit for assessing the influence of logistics innovations on the dynamics of competitiveness, while accounting for regional disparities, changes in transport export routes, and transformations in value chains, remains underdeveloped.

Existing approaches are mainly oriented towards macro-level infrastructural characteristics or general indicators of efficiency (Moyano-Londoño et al., 2025), whereas the mechanisms of redistributing logistics risks, adapting to spatial constraints, and forming new configurations of market presence at the micro-level remain insufficiently formalised (Zheng & Wang, 2025).

Thus, the concept of innovation-logistics mechanisms for the development of agricultural enterprises' competitiveness, which considers the spatial transformation of the economy as a system-forming factor, requires further theoretical substantiation and methodological development. The elimination of these unresolved issues is a necessary prerequisite for making effective managerial decisions aimed at ensuring stable competitive positions for agricultural enterprises amid structural and territorial changes.

3. Methodology.

3.1. Conceptual Model of the Study.

The methodological basis of the study was developed with the need for a comprehensive analysis of the relationship between the transformation of export logistics channels and the competitiveness of enterprises in the agricultural sector under conditions of spatial changes in the economy. The research logic combines the theoretical generalisation of scientific approaches to the interpretation of logistics innovation mechanisms with a quantitative analysis of the dynamics of production and logistics indicators in Ukraine's agricultural sector.

The methodological approach integrates statistical, index, and comparative analyses, enabling the assessment of the scale of export activity and the structural characteristics of logistics flows.

The conceptual model of this study is based on the assumption that the competitiveness of agricultural enterprises in a transformed economic space is shaped by three interrelated parameters: export volume, degree of diversification of logistics channels, and share of alternative transport routes. Within this model, logistics diversification is considered an instrument for reducing transport risks and increasing the adaptability of the export system to spatial constraints arising from changes in infrastructure, trade corridors and geopolitical conditions. Accordingly, the assessment of the logistics component of competitiveness is conducted by integrating production and transportation indicators into a single analytical index.

3.2. System of Indicators and Operationalisation of Variables.

To quantitatively assess the degree of diversification of logistics channels, a modified Herfindahl–Hirschman Index was used based on the sum of the squares of the shares of individual transport modes in the export structure. The obtained value is transformed into a diversification indicator, allowing high index values to be interpreted as evidence of a multichannel logistics configuration. In contrast, values close to zero reflect the concentration of transportation within a single transport channel. To ensure the comparability of indicators across different dimensions, a normalisation procedure using the min–max method was applied, converting all parameters to a dimensionless interval from 0 to 1.

The integration of the obtained indicators is achieved by forming a Logistics Competitiveness Index (LCI), calculated as the average of the normalised indicators for export volume, diversification index, and share of alternative routes. Such an approach allows the parameters characterising different aspects of the logistics system to be harmonised and their combined influence on the competitive positions of agricultural exports to be reflected.

3.3. Data and Sample.

The empirical basis of the study consists of statistical data from the State Statistics Service of Ukraine, the State Customs Service of Ukraine, and sectoral analytical sources that characterise indices of agricultural production, volumes of goods movement across the customs border, the structure of maritime transport, and the distribution of agricultural exports by transport type during the period 2014–2024. The time series analysis of these indicators enables tracing the transformation of the logistics configuration of agricultural exports under wartime and infrastructural shocks.

3.4. Methods of Analysis and Limitations.

Simultaneously, the methodological approach used has certain limitations, primarily related to the aggregated nature of the statistical data and their macro-level characteristics. The calculations are based on generalised indicators of agricultural exports, which do not fully account for differences among individual enterprises, regions and commodity groups. In addition, the proposed model does not consider transportation costs, the duration of logistics operations, or the level of insurance risk.

However, these factors may also influence the formation of a competitive position. Despite these limitations, the proposed methodological toolkit enables the reproduction of the general patterns of transformation in the logistics structure of agricultural exports and assessment of their influence on the dynamics of the agricultural sector’s competitiveness.

4. Results.

The transformational processes that have encompassed the national economy of Ukraine in recent years have significantly changed the conditions for the functioning of agricultural enterprises, primarily in terms of the organisation of export flows and access to external markets (Belova et al., 2025; Countryman et al., 2025).

Changes in transportation geography, the redistribution of transport corridors, and the strengthening of the role of alternative routes require careful consideration.

This necessitates a comprehensive analysis of the dynamics of production indicators and logistics parameters in their interrelationships. An important element of such an analysis is the assessment of the place of the agricultural sector within the structure of national economies, which enables the determination of agriculture's relative role in the formation of gross domestic product.

A comparative analysis of the share of agriculture, forestry, and fisheries in the GDP of selected countries worldwide in 2014–2024 (Table 1) indicates significant cross-country differentiation in the role of the agricultural sector in the economic structure. In most developed countries, a relatively low share of agricultural production in GDP is characteristic, generally fluctuating between 0.7% and 2.0%. In particular, in the United States, this indicator during the study period ranged from 0.8–1.2%, in Germany, from 0.7–1.0%, and in Belgium, less than 1%. In contrast, in countries with a more pronounced agricultural specialisation, such as Brazil and China, the agricultural sector's share is significantly higher at 5–7%.

Table 1. Dynamics of Agriculture's Share in GDP in National Economies, 2014–2024.

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
USA	1.17	1.03	0.94	0.95	0.90	0.84	0.95	0.96	–	–	–
Netherlands	1.80	1.81	1.86	1.97	1.76	1.76	1.74	1.65	1.64	1.75	1.73
Brazil	4.33	4.32	4.89	4.60	4.42	4.21	5.71	6.56	5.77	6.02	5.75
Germany	0.92	0.71	0.73	0.86	0.74	0.83	0.73	0.75	0.99	0.93	0.91
France	1.46	1.50	1.34	1.43	1.53	1.41	1.46	1.46	1.72	1.48	1.30
China	8.48	8.22	7.90	7.33	6.92	7.01	7.54	7.09	7.15	6.89	6.78
Spain	2.53	2.72	2.82	2.80	2.70	2.52	2.78	2.77	2.37	2.61	2.75
Italy	1.91	1.99	1.85	1.89	1.86	1.82	1.93	1.83	1.89	1.86	2.00
Canada	1.59	1.87	1.86	1.89	1.70	1.70	1.84	1.60	–	–	–
Belgium	0.72	0.75	0.67	0.73	0.66	0.72	0.71	0.65	0.67	0.77	0.79
Ukraine	10.15	12.06	11.73	10.18	10.14	8.97	9.31	10.89	8.57	7.55	7.11

Source: based on World Bank Open Data (2025).

The systematisation of data for the entire period made it possible to determine the average values of the share of the agricultural sector in the GDP of the countries studied (Fig. 1). The highest average indicator during 2014–2024 is characteristic of Ukraine, where the share of the agricultural sector amounted to approximately 9–10% of the GDP. For comparison, in Brazil this indicator was around 5%, in China more than 7%, whereas in most European countries it did not exceed 2–3%. This structure indicates a significantly greater role for agricultural production in Ukraine's economic system than in most developed economies.

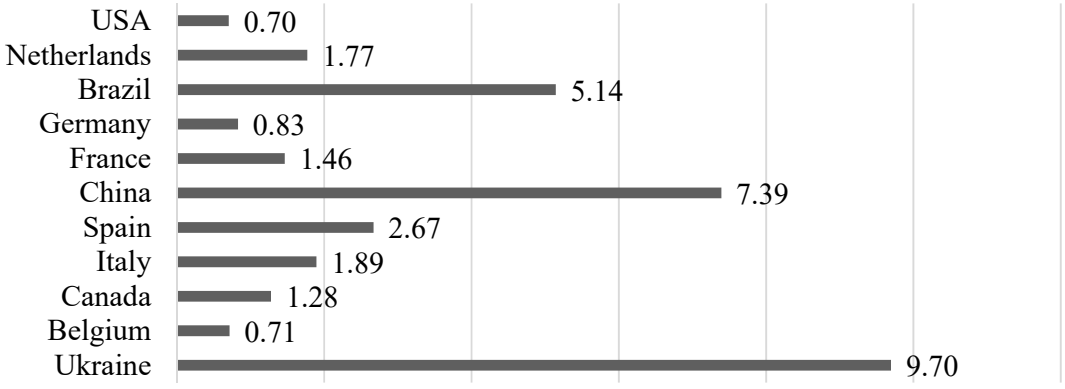

Fig. 1. Average Share of the Agricultural Sector in the GDP Structure in 2014–2024.

Source: based on World Bank Open Data (2025).

Thus, the agricultural sector plays a crucial role in shaping Ukraine's economic structure. The high share of agricultural production in GDP increases the economy's sensitivity to disruptions in agri-food chains, particularly to changes in logistics routes, transformations in export infrastructure, and fluctuations in global agricultural markets. For this reason, the study of the logistical parameters of agricultural exports and their influence on enterprise competitiveness becomes especially relevant under conditions of spatial transformation of the economy.

It is advisable to consistently examine agricultural production indices, the structure of goods movement across customs borders, and indicators of diversification of logistics channels as key characteristics of the adaptation of agricultural exports to spatial changes in the economy. The dynamics of agricultural production indices (Fig. 2) reflect the wave-like characteristics of the sector's development during the study period. From 2014 to 2019, the indices fluctuated between 95.2% and 108.2%, indicating relative stability in production activity despite cyclical fluctuations.

The deterioration in indicators from 2020 to 89.9% was associated with the combined effects of weather factors and macroeconomic constraints. In contrast, in 2021, a 116.4% growth was recorded, reflecting the realisation of deferred production potential and favourable price conditions. The most critical year was 2022, when the index declined to 74.7%, which objectively correlates with military events, the loss of part of production capacity, and disruptions to logistics chains. In 2023, a partial recovery to 111.1% was observed; however, in 2024, the indicator again decreased to 96.6%, indicating the persistence of structural constraints and instability in the operating environment.

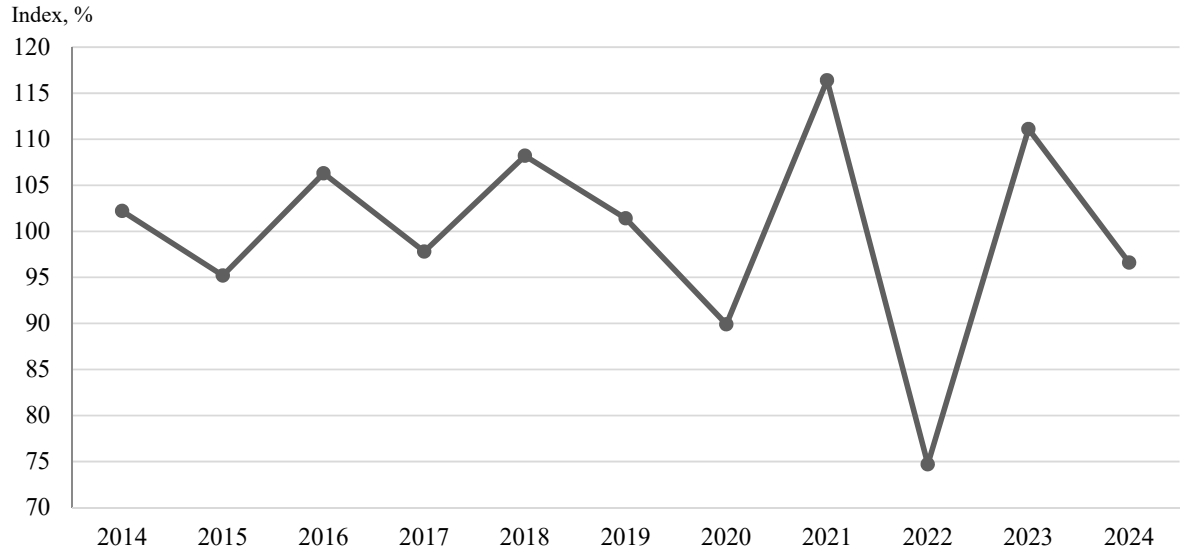

Fig. 2. Dynamics of Agricultural Production Indices in Ukraine, 2014–2024 (%)

Source: based on the State Statistics Service of Ukraine (2025).

Production dynamics cannot be interpreted without accounting for changes in the channels of goods movement across Ukraine's customs borders. The indicators (Fig. 3) demonstrate significant changes in the structure of commodity flows between 2014 and 2024. Until 2021, a gradual increase in the volume of movement through maritime checkpoints was observed, from 140.9 million tonnes in 2014 to 228.7 million tonnes in 2020.

The maritime direction remained the dominant export channel, ensuring relatively low transportation costs and large-scale delivery. In 2022, the volume of transportation through maritime checkpoints sharply decreased to 76.9 million tonnes, which is a reduction of more than three times compared to 2021. This change resulted from the blocking of port infrastructure and the reorientation of export flows.

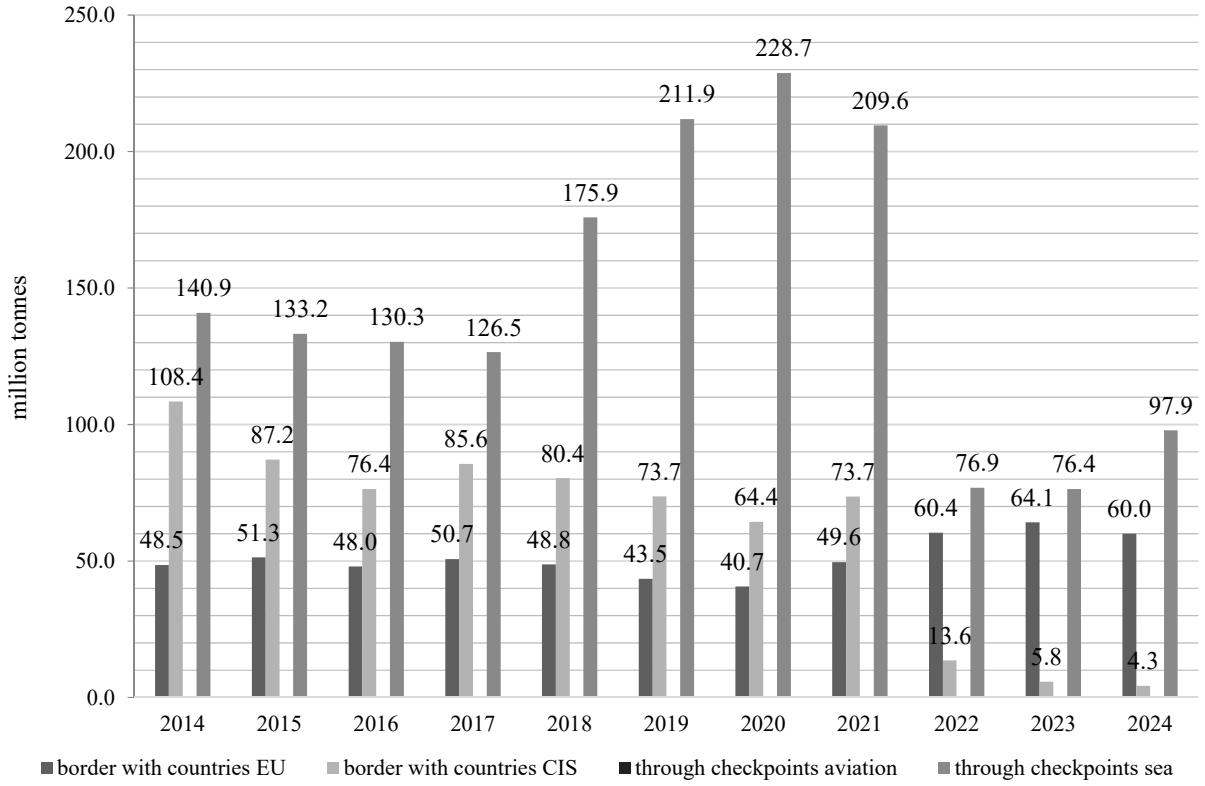

Fig. 3. Foreign Trade Goods Movement in Ukraine, 2014–2024 (million tonnes).
Source: based on the State Customs Service of Ukraine (2025).

Simultaneously, the load on land routes increased, particularly at the border with EU countries, which became strategically important in 2022–2024. While in 2014–2019, the volumes of movement across the border with the EU fluctuated between 43.5 and 51.3 million tonnes, in 2023–2024, they stabilised at around 60 million tonnes (State Customs Service of Ukraine, 2025).

This indicates a structural restructuring of logistics flows and the formation of a new geography of exports, where the role of railway and road connections with European Union countries is increasing.

A more detailed picture of the changes in maritime logistics is presented in Figure 4, which shows the dynamics of transportation through maritime checkpoints and the share of agricultural products at these checkpoints.

Until 2020, the total volume of maritime transportation increased, reaching 228.73 million tonnes, of which agricultural products accounted for 47.3 million tonnes. In 2021, a slight reduction in the total volume to 209.63 million tonnes was recorded, but the share of agricultural products remained relatively stable.

In 2022, total maritime traffic declined sharply to 76.85 million tonnes, and agricultural product volume decreased to 28.8 million tonnes. In 2023–2024, a gradual recovery was observed. In 2024, the total volume through maritime checkpoints amounted to 97.91 million tonnes, of which 60.3 million tonnes were agricultural products. The agricultural sector emerged as a key beneficiary of the restoration of the maritime corridor, underscoring its strong export orientation and adaptability to new conditions.

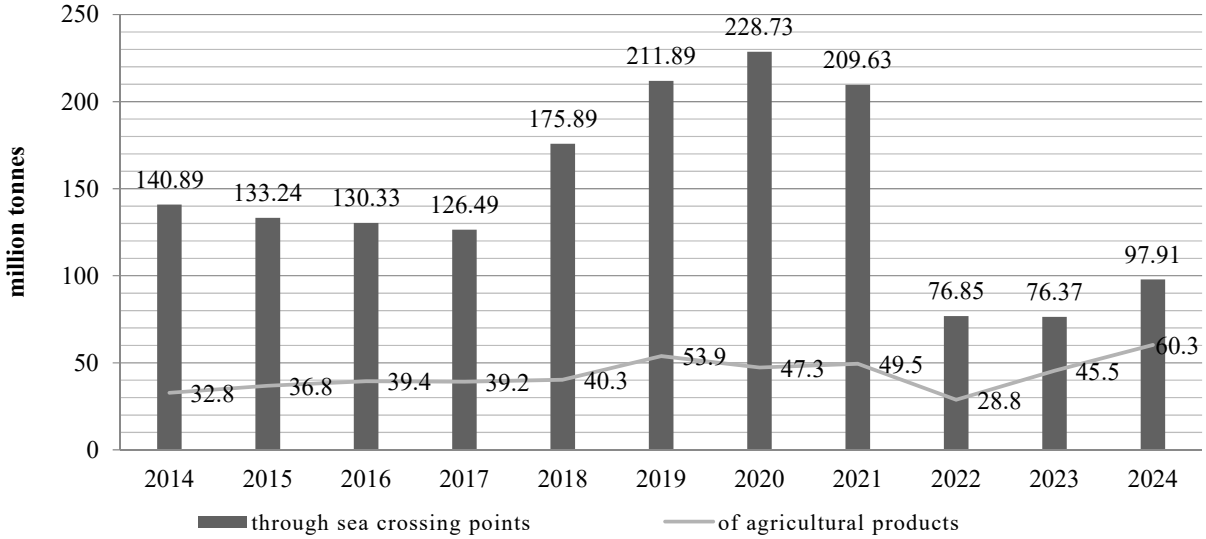

Fig. 4. Maritime Goods Movement in Ukraine, 2014–2024 (million tonnes).

Source: based on the State Customs Service of Ukraine (2025).

Structural shifts in logistics support for agricultural exports are shown in Fig. 5. In 2021, 98% of exports were carried out by maritime transport, in 2022, its share decreased to 75%, while railway transport increased to 16% and road transport to 8%. In 2023, the share of maritime transport was 76%, and in 2024, it increased to 88%, indicating a partial recovery in maritime logistics. Simultaneously, the diversification of export channels is maintained: railway and road transport retain a larger share than in the pre-war period, forming a multichannel logistics support model. The results indicate that spatial changes in the economy have significantly transformed the conditions for the operation of agricultural enterprises, primarily by altering the parameters of logistics processes, including transportation costs, delivery duration, and the reliability of transport routes.

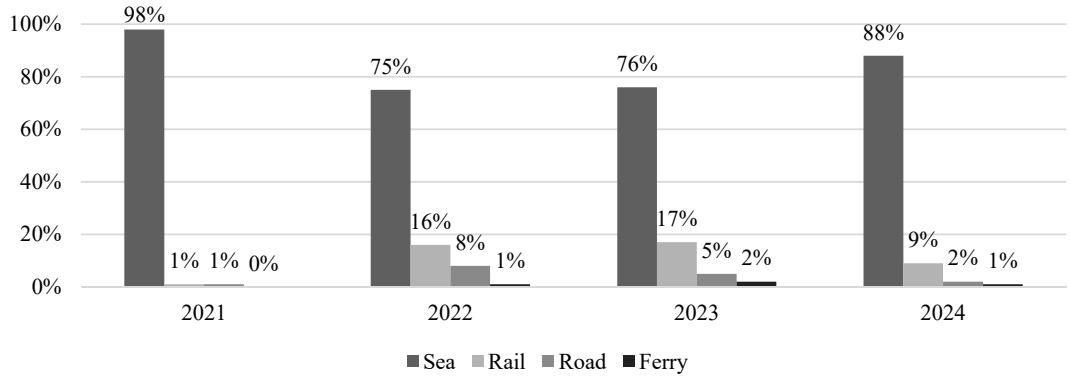

Fig. 5. Structural Dynamics of Logistics Support for Exports of Agricultural Sector Products (2021–2024), %.

Source: based on Agribusiness of Ukraine (2025), State Statistics Service of Ukraine (2025).

The 2022 blockade of maritime routes caused a sharp increase in logistics costs, overloading railway and road infrastructure, and a temporary reduction in production and export activity.

Simultaneously, the forced reorientation to alternative routes and the gradual restoration of maritime connections in 2023–2024 helped partially level logistics imbalances and contributed to the stabilisation of the sector.

Under such conditions, the formation of innovation-logistics mechanisms for the development of competitiveness requires consideration of the need for the prompt redistribution of flows, integration into various transport corridors, and reduction of spatial risks, since it is precisely the ability to structurally adapt that determines the level of resilience of agricultural enterprises within the transformed economic environment.

Therefore, it is appropriate to proceed to a quantitative assessment of the extent to which changes in the configuration of transport routes actually strengthen or, conversely, limit the logistics component of the competitiveness of agricultural exports. For this purpose, a diversification index of logistics channels was applied, constructed from a modified Herfindahl–Hirschman Index. In the initial calculations (Table 2), for each year of 2021–2024, the volumes of exports of agricultural sector products and the shares of the main transport modes in the total volume of transportation were determined: maritime, railway, road, and ferry transport. On this basis, the total share of land (alternative to maritime) routes was also calculated as a characteristic of the degree of reorientation of flows towards land corridors. The calculated diversification index, which ranges from 0 (high concentration of transportation within a single channel) to 1 (increasing diversification), shows a sharp contrast between the pre-war logistics model and the wartime configuration.

Table 2. Calculation of the Logistics Competitiveness Index.

Sequence of calculations	Indicator	2021	2022	2023	2024
Export volume of agricultural sector products	Y_t	60.0	51.0	62.0	70.0
Shares of transport types	$S_{sea,t}$	0.98	0.75	0.76	0.88
	$S_{rail,t}$	0.01	0.16	0.17	0.09
	$S_{road,t}$	0.01	0.08	0.05	0.02
	$S_{ferry,t}$	0.00	0.01	0.02	0.01
Share of land (alternative) routes	$L_t = S_{rail,t} + S_{road,t}$	0.02	0.24	0.22	0.11
Diversification index	$D = 1 - \sum S_i^2$	0.039	0.405	0.391	0.217
Normalisation (min–max method) $X_t^{norm} = \frac{X_t - X_{min}}{X_{max} - X_{min}}$	Y_t^{norm}	0.474	0.000	0.579	1.000
	D_t^{norm}	0.000	1.000	0.960	0.485
	L_t^{norm}	0.000	1.000	0.909	0.409
Logistics competitiveness index formula (equal weights)	$LCI_t = \frac{Y_t^{norm} + D_t^{norm} + L_t^{norm}}{3}$	**0.158**	**0.667**	**0.816**	**0.631**

In 2021, the diversification index was only 0.039, corresponding to a mono-channel structure, with almost all exports carried by maritime transport and the share of land routes not exceeding 2%. In 2022, the value of D increased to 0.405, while the combined share of railway and road transport rose to 0.24, reflecting a forced large-scale transition to multichannel logistics following the port blockades. In 2023, the diversification index slightly decreased to 0.391, with a minor reduction in the share of land routes to 0.22, indicating partial stabilisation and the gradual restoration of the maritime channel's role while maintaining structural multichannality.

In 2024, D decreased to 0.217 and the share of land routes to 0.11, interpreted as a partial return to a more concentrated maritime trade model.

A joint analysis of the diversification index dynamics and export volumes (Fig. 6) reveals several important patterns. First, the transition from almost complete logistics mono-concentration in 2021 to a high level of diversification in 2022–2023 was accompanied by a temporary decline in export volume in 2022 to 51 million tonnes. However, in 2023, against the backdrop of the sustained high value of *D*, export volume increased to 62 million tonnes.

Second, in 2024, a further increase in exports to 70 million tonnes occurred simultaneously with a decrease in the diversification index, indicating that the growth in volumes was achieved not so much through multichannel logistics as through the restoration of capacity in the basic maritime corridor. Thus, diversification at the stage of shock transformation served as an adaptive mechanism, enabling the maintenance of market presence and creating preconditions for further export expansion.

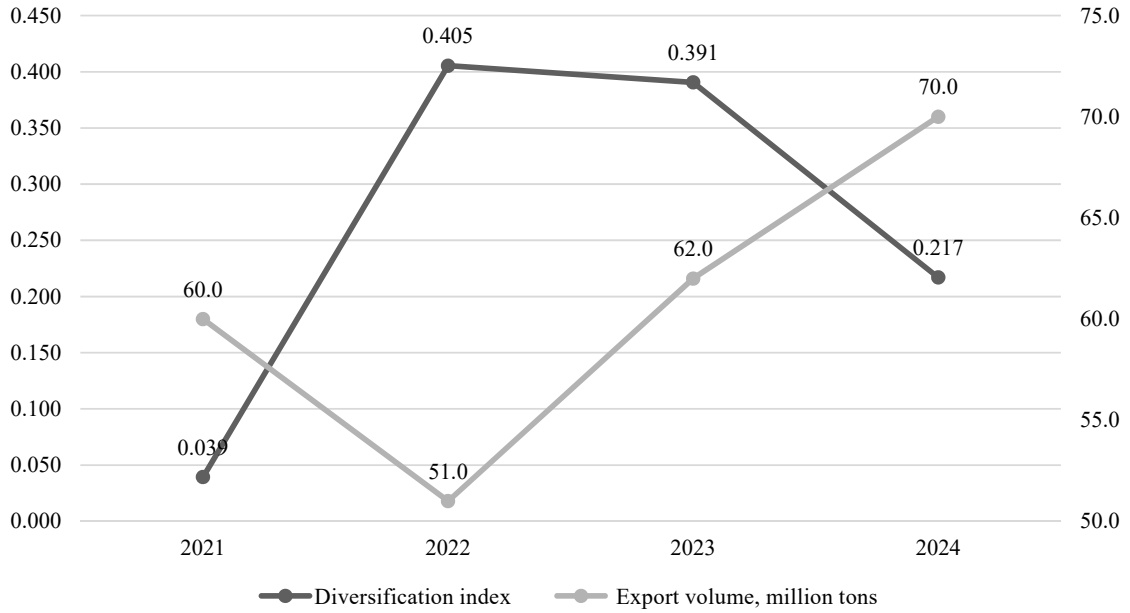

Fig. 6. Dynamics of the Logistics Diversification Index of Export Logistics Channels and the Export Volume of Agricultural Sector Products.

To quantitatively assess the integral contribution of logistics changes to the formation of competitive positions in the agricultural sector, a Logistics Competitiveness Index (LCI) was constructed, with the calculation structure presented in Table 2.

At the first stage, each of the three key indicators – export volume Y_t, the diversification index D, and the share of land routes L_t – was normalised using the min–max method to the range 0-1. Zero values corresponded to the worst situation among the considered years, whereas unit values corresponded to the best.

This approach ensures the comparability of parameters with different dimensions and scales. In the second stage, the Logistics Competitiveness Index was calculated as the arithmetic mean of the three normalised components, reflecting equal importance for export volume, degree of diversification, and the intensity of use of alternative routes.

The calculated LCI values demonstrate a clear transition from a vulnerable mono-channel model to a more resilient and diversified logistics configuration. In 2021, the LCI was 0.158, reflecting moderate export volumes, minimal diversification, and almost complete dependence on maritime transport. In 2022, the index value increased to 0.667.

Although export volumes were the lowest among the analysed years, the maximum values of D^{norm} and L^{norm} indicate a radical restructuring of logistics routes, strengthening the adaptive potential of agricultural export. In 2023, the LCI reached its peak of 0.816, as it combined a high level of diversification with the recovery of export volumes and a significant role for land corridors. In 2024, the index decreased to 0.631, and a record export volume was accompanied by a decline in diversification and a reduction in the role of alternative routes, signalling a tendency for the system to concentrate logistics risks.

The calculation of the Logistics Competitiveness Index (Fig. 7) enables tracing the trajectory of the transition from a mono-channel to a diversified logistics configuration. The increase in the index from 0.158 in 2021 to 0.816 in 2023 characterises a period of intensive logistics transformation, during which enterprises and the state simultaneously sought new routes, combined different modes of transport, adapted infrastructure to the requirements of land corridors, and changed contract structures. The subsequent decrease to 0.631 in 2024 indicates not so much a degradation of the logistics system as a shift in the balance between export volumes and the distribution of flows, as some land routes lose part of their load amid the restoration of the maritime corridor.

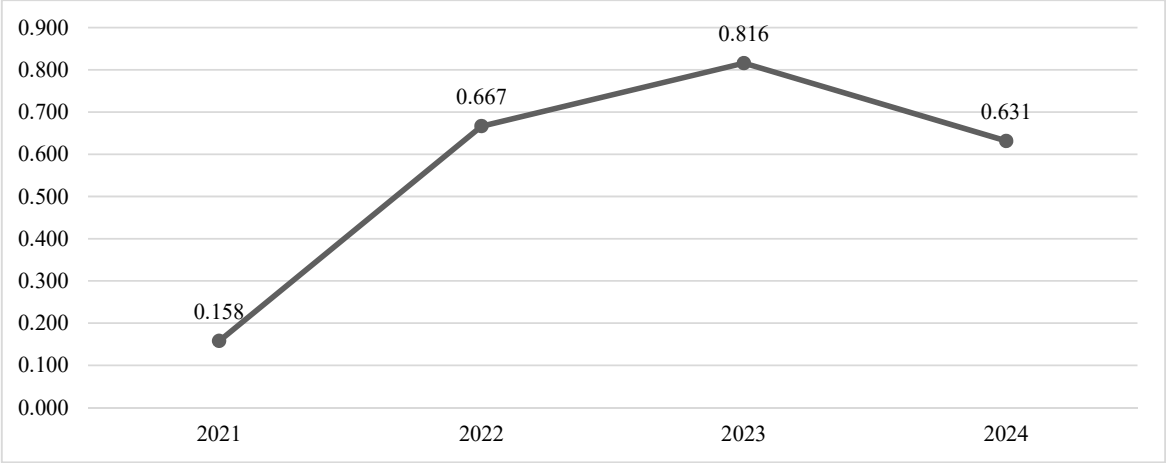

Fig. 7. Dynamics of the Integral Logistics Competitiveness Index of Agricultural Exports, 2021–2024.

The logistics component of the agricultural sector's competitiveness is determined not so much by the magnitude of export volumes as by the structure and configuration of the channels through which they are ensured. The most balanced combination of export flow scale and logistics system resilience was recorded in 2023, when relatively high export volumes were accompanied by substantial diversification of transport routes and a noticeable role of land corridors in the logistics system. In contrast, in 2024, the strengthening of dependence on a single type of transport, despite further increases in export volumes, led to a decrease in the overall Logistics Competitiveness Index.

The obtained parameters enable the quantitative reproduction of the transition trajectory from a mono-channel to a diversified logistics model. This substantiates the view that maintaining a multichannel transportation structure is a necessary prerequisite for the effectiveness of innovation-logistics mechanisms to enhance the competitiveness of agricultural enterprises.

5. Conclusions.

The study confirms that under conditions of spatial transformation of the economy, the competitiveness of enterprises in the agricultural sector is determined not only by production characteristics or export dynamics, but primarily by the structure of logistics channels through which export potential is realised. The analysis of agricultural production indices indicates the cyclical nature of the sector's development and its sensitivity to external factors.

However, it was precisely the logistics constraints of 2022 that became the decisive factor in the sharp decline in production and export activity. The blocking of maritime routes caused not only a reduction in the physical volumes of exports but also a profound restructuring of the system of goods movement across the customs border, with flows being redistributed in favour of rail and road transport.

The diversification index for logistics channels showed a transition from near-complete monoculture in 2021 to high diversification in 2022 and 2023.

This serves adaptive and compensatory functions amid the destruction of traditional maritime logistics systems. The application of the integral Logistics Competitiveness Index, which combines export volumes, degree of diversification, and share of alternative routes, showed that the logistics system's highest resilience corresponds to the configuration in 2023, when the multichannel transportation structure yielded the index's maximum value.

Simultaneously, in 2024, despite record export volumes during the study period, the strengthening of concentration in maritime transport was accompanied by a decline in the integral indicator, indicating the reproduction of structural vulnerability in the logistics system and the need for targeted support for a diversified model.

Logistics diversification is a distinct instrument for increasing competitiveness, as it reduces transport risks, enhances flexibility in the redistribution of export flows, and creates alternative routes to external markets. The effectiveness of innovation-logistics mechanisms is manifested not only in increased sales volumes but primarily in achieving structural balance in supply channels, thereby limiting spatial asymmetry and reducing critical dependence on a single transport mode.

Further research is required to improve methodological approaches for assessing logistics competitiveness at individual enterprises and regions, taking into account transportation costs, delivery duration, insurance risks, and the degree of digitalisation of flow management. A promising direction is to supplement the integral model with indicators of infrastructure capacity utilisation, the digital integration of logistics processes, and institutional restrictions on access to international transport corridors.

The development of scenario models for export logistics is important, given potential changes in geopolitical conditions and Ukraine's integration into the European economic space. This approach will shift from post-factum recording of changes to the development of predictive tools for managing innovation-logistics mechanisms, thereby enhancing the competitiveness of enterprises in the agricultural sector.

Conflict of Interest Statement.

The authors declare that there is no conflict of interest.

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