Transformations and Sustainability, 2026; **2**(4): 326–336
https://doi.org/10.63775/853svq06

Entropic development of the logistics system for agricultural trade in Ukraine: A structural-dynamic dimension of transcendental changes

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Abstract

The article investigates the entropic development of the logistics system of Ukrainian agro-trade under conditions of transcendence characterized by uncertainty, turbulence, nonlinear transformations, and the emergence of fundamentally new factors influencing economic processes. The study aims to identify the structural and dynamic trends of logistics system development in the context of military challenges, disruption of traditional supply chains, transformation of export routes, and increasing complexity of logistics flows. The methodological framework integrates systemic, entropic, evolutionary, and resilience-based approaches, enabling the logistics system of agro-trade to be considered as a complex adaptive system capable of self-organization and adaptation under the influence of entropy-generating factors. The research examines the impact of the war on the functioning of agro-logistics, changes in transportation structures, the formation of alternative export corridors, and the emergence of new logistics hubs. It is established that the increase in entropy is manifested through growing uncertainty, disruption of established supply chains, rising transportation costs, uneven distribution of logistics capacities, and increased dependence on border and port infrastructure. Simultaneously, entropy acts not only as a destructive factor but also as a catalyst for adaptive transformations, stimulating the development of multimodal transportation, digital logistics platforms, alternative trade routes, and new forms of logistics coordination. The findings demonstrate that Ukraine's agro-trade logistics system is gradually transforming from a state of instability and disorganization toward a new level of structural order based on flexibility, diversification, network interaction, and resilience. The practical significance of the research is associated with the possibility of applying the proposed approach to the development of anti-entropic management mechanisms aimed at strengthening the sustainability, adaptability, and competitiveness of Ukraine's agro-trade logistics system.

Keywords: corporate hypocrisy, greenwashing, social washing, systematic literature review, institutional theory, legitimacy theory, stakeholder theory, market distortion, ESG.

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Received 7 June 2026; **Accepted** 17 November 2026; **Published** 20 November 2026

1. Introduction

In the context of deepening global determinants of instability, military challenges, transformation of global supply chains, and increasing uncertainty in the economic environment, it is the logistics system of Ukrainian agro-trade that is undergoing significant structural and functional changes. At the same time, for Ukraine, the agricultural sector remains one of the key drivers of the national economy and provides a significant share of the state's export revenues, which highlights the need to find new approaches to ensuring the sustainability, adaptability, and efficiency of logistics processes. Undoubtedly, the current stage of socio-economic system development is characterized by a transition toward a state of "transcendence"—a condition in which the traditional patterns governing economic systems lose their predictability under the influence of non-linear, highly unpredictable, and interconnected changes. Under these circumstances, the entropy-based approach gains particular scientific significance, it enables the assessment of uncertainty, disorganization, and the loss of order within the agricultural trade logistics system, while also revealing the mechanisms that shape new trajectories for its development.

Despite the significant contributions made by scholars to the study of logistics systems, supply chain management, and the development of the agricultural sector, the assessment of entropic processes within agricultural trade logistics systems—specifically in the context of these transcendent changes—remains insufficiently explored. Particular attention should be paid to studying the structural-dynamic characteristics of such systems, identifying sources of entropy and the patterns of its accumulation, and examining the mechanisms by which destructive processes are transformed into drivers of development.

In this regard, the study of the entropic development of the logistics system of Ukrainian agri-trade through the prism of the structural-dynamic dimension of transcendental changes is timely and scientifically sound, as it is aimed at forming practical recommendations for ensuring the adaptability, resilience and competitiveness of domestic agri-trade in the conditions of the new economic reality.

2. Literature review

Research into the entropic development of the logistics system for agricultural trade in Ukraine emerges at the intersection of scholarly work concerning agricultural trade, digital transformation, logistics, uncertainty management, and the resilience of economic systems. An analysis of contemporary academic literature reveals a gradual shift in focus—moving away from traditional approaches to managing agricultural trade and toward the study of complex, non-linear processes driven by turbulence, global crises, and profound, far-reaching transformations.

An important foundation for the study of agro-trade lies in works dedicated to the conceptual underpinnings of its development. Specifically, Iatsenko (2022) substantiates a modern conceptual framework for agro-trade, defining it as a complex economic system that integrates production, trade, and logistics processes within a unified market space. The author highlights the growing role of institutional and

innovative factors in determining the competitiveness of agricultural trade in the context of globalization (Iatsenko, 2022). These ideas are further developed in a study by Iatsenko et al. (2025), which outlines the architecture of an innovative agro-trade ecosystem in the era of digitalization, involving the integration of information platforms, digital services, and logistics networks.

Research into the impact of global uncertainty and wartime challenges has also made a significant contribution to understanding the contemporary transformations of agricultural trade. For instance, Mykhailova et al. (2023) demonstrate that the war in Ukraine has triggered a major restructuring of international food supply chains, altered the geography of trade flows, and underscored the need to enhance the resilience of logistics systems. Similarly, Zavadska et al. (2025) emphasize the necessity of establishing stable and resilient mechanisms for international agricultural trade amidst global uncertainty—a matter of particular importance for countries that export agricultural products. In recent years, issues related to the logistics support of agricultural trade have gained particular significance. Riepina, Sadovnyk, and Ivashchenko (2025) proposed a concept for a monitoring dashboard designed to assess the state of the logistics system within Ukrainian agricultural trade amidst turbulence; this tool enables the real-time tracking of critical operational parameters across logistics networks. Further exploration of logistics-related challenges is presented in a study by Riepina et al. (2026), which examines contemporary challenges and development opportunities for agricultural trade logistics through the lens of an anti-entropic approach. The authors argue for the necessity of establishing mechanisms to reduce entropy by developing transport infrastructure, digitizing logistics processes, and enhancing the adaptability of management systems.

Digitalization serves as a crucial factor in the transformation of agricultural trade. Garafonova et al. (2025) identify digitalization as a key driver of structural change within the global economic environment. The researchers emphasize that digital technologies contribute to greater transparency in business processes, improved managerial decision-making, and reduced transaction costs. A similar perspective is held by Shlapak et al. (2023), who demonstrate that the digital transformation of international trade is accompanied by the emergence of technological innovations and a shift in investment priorities. Meanwhile, Tsygankova et al. (2023) highlight the impact of Industry 4.0 technologies on companies' strategies for entering global markets, which creates new opportunities for integrating logistics processes into unified digital ecosystems.

The issues of global imbalances, asymmetries, and uncertainty are also significant for the study of entropic processes. Tananaiko et al. (2023) substantiate the economic nature of asymmetries within the global trade system and demonstrate that their intensification generates additional uncertainty in the functioning of international commodity markets. Meanwhile, Mozgovyy et al. (2023) examine the factors influencing the choice of investment models in international business, arguing that the volatility of the external environment and associated risks must be taken into account when formulating development strategies.

The issues surrounding the assurance of sustainable development and efficiency in the agricultural sector are addressed in the works of Sadovnyk et al. (2025), who propose an innovative development model for agricultural enterprises within a sustainability framework, as well as Sas and Mykolaichuk (2023), who examine the improvement of cost management systems in agricultural enterprises. The findings underscore the necessity of integrating economic efficiency, innovation, and adaptability as prerequisites for reducing the entropy inherent in the operations of agricultural enterprises. Thus, an analysis of the literature reveals that the digitalization of agricultural trade, the development of logistics systems, the sustainability of agricultural trade, and the management of uncertainty have been extensively explored. However, the concept of entropic development within the logistics systems of Ukraine's agricultural trade—specifically under conditions of «transcendence». Existing scholarly work focuses primarily on digital transformation, logistics resilience, and anti-entropic mechanisms; meanwhile, the specific processes by which entropy is generated, accumulated, and mitigated amidst transcendent shifts in the economic environment have yet to receive a comprehensive theoretical and methodological grounding. It is precisely this research gap that necessitates further study in this area.

3. Methods

The methodological approach of the study is based on the integration of systems, entropy, evolutionary, and resilience perspectives. This allows the logistics system of Ukraine's agricultural trade sector to be viewed as a complex adaptive system, the development of which is shaped by entropy-generating factors and accompanied by processes of self-organization, structural reconfiguration, and the emergence of new development opportunities. In the context of a grant proposal, this enables the combination of classical logistics approaches with a modern paradigm for analyzing economic systems characterized by uncertainty, turbulence, and transcendence.

4. Results

The study established that, following 2022, Ukraine's agricultural trade logistics system underwent unprecedented transformations driven by wartime challenges, the blockage of traditional export routes, the destruction of transport infrastructure, and the urgent need to redesign logistics chains. The closure of seaports, shifts in foreign trade directions, the redirection of cargo flows toward western border crossings, and the growing role of multimodal transport have triggered large-scale structural shifts within Ukraine's agricultural trade system. Under these conditions, the agricultural trade logistics system has evolved into a complex adaptive system operating amidst heightened uncertainty, non-linearity, and profound, transformative changes. In this context, such profound change manifests through the emergence of new development factors that transcend traditional models for forecasting logistics processes and alter the established operational mechanisms of export-oriented supply chains. The use of an entropy-based approach is becoming particularly relevant, as it allows for the

assessment of the degree of disorganization in logistics flows, the level of uncertainty in transport and export operations, and the intensity of structural changes within the agro-trade system. According to I. Prigogine's concept of open systems, periods of crisis-driven transformation are accompanied by an increase in entropy—manifesting as the breakdown of established connections, a loss of stability, and the emergence of new configurations of interaction among economic agents.

In the logistics system of Ukraine's agricultural trade sector, the increase in entropy—or «entropic load»—has manifested through:

- a reduction in the throughput capacity of specific logistics routes;
- the disruption of traditional export supply chains for grain and oilseed products;
- an increase in transport costs and delivery risks;
- a shift in the utilization structure of transport vehicles and export channels;
- an uneven distribution of logistics capacities across different regions;
- a heightened dependence of exports on border and port infrastructure.

At the same time, this rise in entropy has acted as a catalyst for self-organization within the logistics system. In response to external challenges, new developments have emerged: the creation of alternative transport corridors, the expansion of "dry ports" and border infrastructure, the diversification of logistics routes, and an intensification of multimodal transport operations. Consequently, a new architecture for agricultural logistics is gradually taking shape—one capable of functioning amidst high uncertainty and continuous transformation. Thus, the entropic evolution of the logistics system within Ukraine's agricultural trade sector is characterized by the simultaneous interplay of disorganization and self-organization. This process involves the emergence of new spatial configurations for logistics flows, a shift in the roles of specific transport hubs, and a fundamental rethinking of strategies for facilitating the nation's food exports. Studying the structural and dynamic aspects of such changes makes it possible not only to assess the consequences of contemporary challenges but also to establish a scientific foundation for managing the development of agrilogistics systems amidst profound uncertainty.

Military hostilities, the blockade of maritime routes, and the transformation of foreign trade ties have significantly impacted the export potential of Ukraine's agricultural trade sector. At the same time, the agricultural sector has maintained its status as a key source of foreign currency earnings, demonstrating a high degree of adaptability to external shocks. The restoration of logistics routes and the diversification of sales channels have contributed to the gradual stabilization of export activities.

Table 1
Entropy factors in the export of Ukraine's agri-food products

Year	Characteristics of the Logistics System	Entropy State
2021	Stable functioning of port logistics	Low
2022	Disruption of traditional export routes	High
2023	Formation of alternative supply channels	Elevated
2024	Partial stabilization of logistics flows	Medium
2025	Diversified export model	Moderate

Source: designed by the authors.

Following 2022, the structure of agricultural product transportation underwent a radical transformation. While seaports played a dominant role prior to the war, the blockade led to a significant increase in the burden on rail, road, and river transport.

Table 2
Structural changes in agro-trade transportation support

Mode of Transport	Before 2022	After 2022
Maritime Transport	Main export channel	Partial reorientation
Rail Transport	Supporting function	Key element of logistics
Road Transport	Limited use	Significant increase in volumes
River Transport	Secondary importance	Important alternative route
Multimodal Transport	Low level of development	Active expansion

Source: designed by the authors.

The intensification of entropic processes within the logistics system has led to a spatial redistribution of transport flows. Border regions and Danube ports have taken on particular significance, emerging as new hubs for the concentration of agrologistical activity.

Table 3
New centers of logistics gravity in ukrainian agro-trade

Region	Logistics Specialization	Significance for Agro-Trade
Odesa Region	Maritime and Danube logistics	High
Zakarpattia Region	Cross-border logistics	High
Lviv Region	Road and rail transportation	High
Chernivtsi Region	Export crossings to the EU	Medium
Volyn Region	Western logistics corridor	Medium

Source: designed by the author

Entropic load is a consequence of the destabilization of traditional transport and logistics links and characterizes the degree of uncertainty in the system's functioning.

In the logistics of agricultural trade, it manifests through increased risks, route changes, and greater variability in transport solutions.

Table 5
Factors shaping entropy load

Factor	Impact on the logistics system
Blockage of maritime routes	Increased uncertainty
Destruction of infrastructure	Disruption of logistics flows
Changes in export corridors	Reconfiguration of logistics networks
Rising transportation costs	Reduced efficiency
Geopolitical risks	Increased turbulence

Source: designed by the author

Despite a significant increase in entropy, the logistics system for agricultural trade demonstrates a capacity for self-organization and adaptation. The formation of new transport corridors, the development of digital logistics platforms, and the diversification of export channels are gradually shifting the system to a new level of order.

Table 6
Manifestations of self-organization in the agro-trade logistics system

Adaptation direction	Result
Development of Danube ports	Export diversification
Expansion of border infrastructure	Increased export capacity
Multimodal transportation	Greater logistics flexibility
Digitalization of logistics processes	Reduced transaction costs
Formation of new partnership networks	Enhanced resilience

Source: designed by the author.

In other words, it can be argued that the structural-dynamic trends in the entropic development of Ukraine's agricultural trade logistics system—amidst conditions of transcendence—are characterized by heightened uncertainty in the external environment, the transformation of logistics routes, shifts in supply chain configurations, and the emergence of new adaptation mechanisms for agricultural market participants. The rise in the system's entropy manifests as increased complexity in coordinating transport flows, greater information asymmetry, and the necessity for rapid responses to numerous exogenous challenges. Simultaneously, the advancement of digital technologies, the integration of innovative logistics solutions, and the diversification of logistics infrastructure create the prerequisites for mitigating entropic risks and ensuring the sustainable development of the agricultural trade system in the face of transcendent changes

5. Discussion

The results obtained confirm that the development of the logistics system for agricultural trade in Ukraine since 2022 has taken place amidst a significant increase in entropy, driven by both external and internal factors. Unlike traditional approaches to studying agricultural trade logistics—which focus primarily on transportation efficiency, cost optimization, or infrastructure development—the entropy-based approach proposed here allows for viewing the transformation of logistics systems as the outcome of an interplay between processes of disorganization and self-organization. These findings align with the conclusions of O. Iatsenko, who conceptualizes agricultural trade as a complex, integrated system encompassing production, commercial, and logistical interconnections. At the same time, this study expands upon existing academic frameworks by demonstrating that, under conditions of profound instability, the key driver of development is not merely the efficiency of interactions among system components, but also the system's capacity to function amidst high uncertainty and structural turbulence. Consistent with the research of Mykhailova et al., this study confirms that the full-scale war has triggered a radical transformation of international supply chains for agri-food products. However, unlike existing studies, this work demonstrates that the observed changes can be interpreted as a manifestation of entropic development, wherein the breakdown of prior logistics structures is accompanied by the emergence of new mechanisms for coordinating flows and new focal points for logistics activity.

Of particular interest are the findings regarding the formation of an alternative architecture for agricultural logistics. The growing role of border regions, Danube ports, multimodal transport, and digital platforms indicates a gradual transition of the logistics system to a new level of organization. Viewed through the lens of I. Prigogine’s theory of dissipative structures, these results confirm that crisis phenomena serve not merely as a source of destabilization, but also as a catalyst for the emergence of new forms of order. The analysis also demonstrated that the establishment of new export routes is accompanied by a shift in the spatial configuration of the logistics system. While maritime logistics within the Black Sea basin played a dominant role prior to 2022, there is now a diversification of transport flows across road, rail, river, and multimodal modes. This indicates a gradual reduction in the dependence of agricultural trade on specific logistics hubs, alongside an increase in the system's adaptability. At the same time, the research findings highlight the need for the further development of anti-entropic management mechanisms.

Specifically, improvements are required in tools for the digital monitoring of logistics flows, risk forecasting mechanisms, management decision-support systems, and approaches for assessing entropy levels within logistics networks. These areas could serve as the foundation for a new paradigm in managing agricultural logistics amidst profound, transformative changes. The practical value of these findings lies in the potential to apply an entropy-based approach to monitor the resilience of the agricultural trade logistics system, evaluate its adaptability, and forecast future development trajectories. These results can be utilized by government authorities,

agricultural businesses, and logistics operators when developing strategies to ensure food security and expand Ukraine's export potential.

6. Conclusions

The article examines the characteristics of the entropic development of Ukraine's agricultural trade logistics system amidst profound changes in the economic environment. It is established that, following 2022, this logistics system underwent significant structural and dynamic transformations driven by wartime challenges, the disruption of traditional export routes, the restructuring of transport networks, and shifts in the configuration of international supply chains. The study substantiates the utility of an entropic approach for analyzing the development processes of agricultural trade logistics systems. It is demonstrated that rising entropy manifests through increased uncertainty, greater complexity in logistics interconnections, heightened information asymmetry, and the necessity for continuous adaptation to external changes. At the same time, entropy acts not merely as a destructive force but also as a catalyst for the emergence of new self-organization mechanisms and system development. The key structural and dynamic trends in the entropic development of Ukraine's agricultural trade logistics system are identified, including the diversification of logistics routes, the growing role of multimodal transport, the establishment of new logistics hubs, the activation of cross-border infrastructure, the development of export routes via the Danube, and the digitalization of logistics processes.

It is concluded that, under these conditions of profound transformation, the agricultural trade logistics system acquires the characteristics of a complex adaptive system, capable of self-organization in response to entropy-generating factors. The gradual formation of a new logistics architecture indicates a transformation of destructive processes into a source of adaptation and structural renewal. The scientific novelty of this research lies in the development of theoretical concepts regarding the interpretation of the agro-trade logistics system as an open entropic system, which evolves within a context of transcendence through the interplay of disorganization, adaptation, and self-organization. The practical significance of the findings lies in the potential to apply these concepts to develop anti-entropic management mechanisms for agro-trade logistics systems, aimed at enhancing their resilience, adaptability, and competitiveness amidst high levels of uncertainty.

Future research directions include the development of a methodology for the quantitative assessment of entropy within agro-trade logistics systems, the creation of an integral index of entropic development, and the construction of scenario-based models to forecast the behavior of agro-logistics systems under conditions of transcendent change.

Funding

Competition for grants of the President of Ukraine to support scientific research and development for doctoral students "Entropic development of the logistics system of agro-trading in Ukraine under conditions of transcendence" (No. 2025.04/0001).

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