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Enhancing the environmental safety of logistics processes through optimal supply planning

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Abstract*. The study's relevance stems from the growing environmental impact of logistics processes and the need to transition to supply models that focus on reducing emissions and the rational use of resources. In the context of global decarbonization strategies, there is a need for scientific substantiation of approaches that simultaneously improve logistics efficiency and environmental safety. The work aims to develop a theoretical and methodological model for optimal supply planning that minimizes the negative environmental impact of logistics processes and integrates environmental criteria into the supply management system. The methodological basis is a systemic approach, methods for comparative analysis of international logistics efficiency indices, assessment of CO_2 emission dynamics, and tools for environmental and logistics modelling. The work uses structural and functional analysis, which allowed the development of a model for greening logistics processes and a risk-oriented approach to assess environmental risks. The results of the study include a comprehensive scientific substantiation of the principles of greening logistics processes and the development of an integrated approach to* *optimal supply planning in the face of growing environmental requirements. Based on a comparative analysis of international logistics efficiency indices, structural differences between countries with highly developed and fragmented logistics infrastructure have been identified, affecting their ability to decarbonize. A model for increasing the environmental safety of logistics processes has been developed, comprising four key blocks: monitoring, planning, optimization, and assessment of environmental outcomes. Additionally, an environmental safety risk assessment matrix has been developed, which allows identifying critical points of environmental threats and establishing priority areas for improving logistics operations. The proposed tools can be used to form policies for greening logistics and modernizing corporate supply management systems.*

Keywords: *logistics greening, optimal supply planning, environmental risks, low-carbon solutions, logistics performance, CO_2 emissions.*

Підвищення екологічної безпеки логістичних процесів через оптимальне планування постачань

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Анотація. *Актуальність дослідження зумовлена зростанням впливу логістичних процесів на екологічний стан довкілля та необхідністю переходу до моделей постачань, орієнтованих на зниження викидів і раціональне використання ресурсів. У контексті глобальних стратегій декарбонізації постає потреба у науковому обґрунтуванні підходів, що забезпечують одночасне підвищення логістичної ефективності та екологічної безпеки. Метою роботи є розроблення теоретико-методичної моделі оптимального* *планування постачань, спрямованої на мінімізацію негативного впливу логістичних процесів на довкілля та інтеграцію екологічних критеріїв у систему управління постачаннями. Методологічну основу становлять системний підхід, методи порівняльного аналізу міжнародних індексів логістичної ефективності, оцінювання динаміки викидів CO_2, а також інструменти екологічного та логістичного моделювання. У роботі застосовано структурно-функціональний аналіз, що дозволив побудувати модель екологізації логістичних процесів, а також ризик-орієнтований підхід для формування матриці оцінювання екологічних ризиків. Результати дослідження полягають у комплексному науковому обґрунтуванні засад екологізації логістичних процесів та формуванні інтегрованого підходу до оптимального планування постачань в умовах зростання екологічних вимог. На основі порівняльного аналізу міжнародних індексів логістичної ефективності встановлено структурні відмінності між країнами з високорозвиненою та фрагментованою логістичною інфраструктурою, що впливають на їхню здатність до декарбонізації. Сформовано модель підвищення екологічної безпеки логістичних процесів, яка охоплює чотири ключові блоки – моніторинг, планування, оптимізацію та оцінювання екологічних результатів. Додатково розроблено матрицю оцінювання ризиків екологічної безпеки, що дозволяє ідентифікувати критичні точки утворення екологічних загроз та встановити пріоритетні напрями вдосконалення логістичних операцій. Запропоновані інструменти можуть бути використані для формування політик екологізації логістики та модернізації корпоративних систем управління постачаннями.*

Ключові слова: *екологізація логістики, оптимальне планування постачань, екологічні ризики, низьковуглецеві рішення, логістична ефективність, викиди CO_2.*

Problem statement. The intensive development of global supply chains is accompanied by an increase in anthropogenic load, a significant part of which falls on the transport and logistics sector. The increase in transportation volumes, uneven transport flows, infrastructure fragmentation, and low energy efficiency lead to higher greenhouse gas emissions and a deterioration of environmental conditions in the territories where logistics systems operate [1, p. 51]. Traditional approaches to logistics organization are primarily focused on economic indicators and do not adequately account for the environmental consequences of operations. In the context of global decarbonization and increasingly stringent regulatory requirements, there is a need to develop new methodological approaches that integrate environmental criteria into planning and supply optimization [2]. The lack of holistic mechanisms for managing environmental risks in logistics processes underscores the problem's scientific relevance and requires in-depth research.

Analysis of recent research and publications. Modern research in logistics and supply chain management demonstrates a growing focus on greening processes, digitalization, and increased sustainability, reflected in a wide range of approaches proposed by scholars. For example, D. Dubisz and colleagues outlined the key factors in the formation of the carbon footprint in distribution, emphasizing the need for green logistics solutions [3, p. 804], which is consistent with the conclusions of scholars led by M. Borchardt on the barriers and opportunities for managing Scope 3 emissions [4]. Deepening this issue, Z. Ma et al. showed that the development of low-carbon supply chains largely depends on integrating IoT technologies and increasing companies' environmental responsibility [5], which aligns with the emission-optimization model proposed by P. Verma and V. Mishra for carbon cap-and-trade conditions [6]. In the logic of decarbonization solutions, S. Routroy and colleagues identified critical areas of ecological transformation of logistics – from infrastructure solutions to digital monitoring tools [7, p. 2], which is also reflected in the Ukrainian context in the works of N. Reznik and O. Marinina, who

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emphasized the role of «green» logistics in forming a synergistic effect between economic, social and environmental goals [8, p. 62]. In the same context, V. Hatylo developed the ESG-LogiM model, which proves the importance of ESG-oriented strategies for strengthening logistics sustainability [9, p. 144], while A. Ilina emphasized the importance of human capital development as a prerequisite for practical logistics activities [10, p. 305]. The digital vector of logistics development is deepened by the studies of O. Korobkova and Z. Korobkova, who demonstrated the importance of customs logistics in international cargo movements [11, p. 177]. In parallel, L. Kaptosv demonstrated the potential of modern geoinformation platforms for more accurate routing [12, p. 2], and O. Korostin outlined the potential of artificial intelligence to optimize maritime logistics flows [13, p. 31]. Confirmation of the importance of digital transformation in logistics is also found in the work of N. Kantsedal and colleagues, who demonstrated the effectiveness of digital solutions in improving the quality of supply management, transportation, and warehouse operations [14, p. 45]. Continuing this logic, S. Li and T. Sun empirically demonstrated the role of green logistics in reducing the transport industry’s emission intensity [15], while F. Jia and colleagues clarified the factors of sustainable supply chain design and its impact on environmental performance [16, p. 581]. Concluding the review of approaches, a team of authors led by M. Ivanova substantiated the importance of statistical methods in risk management of logistics and foreign economic operations under uncertainty [17, p. 241].

Therefore, a body of modern scientific work demonstrates the consolidation of environmental, digital, and management approaches, which form the foundation for the creation of new-generation, sustainable, adaptive, and low-carbon logistics systems.

Highlighting previously unresolved parts of the general problem. Despite significant scientific achievements, several key issues remain unresolved, in particular, regarding the coordination of environmental standards with the

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operational reality of enterprises, the integration of digital tools in the model of «green» logistics, the quantitative measurement of environmental risks and the determination of optimal parameters of low-carbon efficiency in conditions of high dynamics of logistics flows. That is why our research aims to systematize approaches to greening logistics processes and to develop a holistic model that integrates methods of optimal supply planning with modern tools for controlling environmental risks. The practical value of the results lies in the possibility of formulating applied recommendations for enterprises to reduce environmental load, improve mechanisms for selecting environmentally sound routes, assess environmental threats, and introduce low-carbon efficiency indicators into the logistics process management system.

Formulation of the article objectives (task statement). The purpose of the study is to theoretically substantiate and develop a model for increasing the environmental safety of logistics processes by integrating methods of optimal supply planning, environmental risk assessment tools, and low-carbon efficiency indicators, thereby reducing environmental load and increasing the sustainability of logistics systems.

Presentation of the main material of the study. In modern conditions, environmental safety is becoming a key element of the strategy for the sustainable development of enterprises, because logistics systems account for a significant share of anthropogenic impact. The primary sources of environmental risk are the complexity of logistics operations. The most significant load is created by transport, which is characterized by high fuel consumption and emissions of greenhouse gases, nitrogen oxides and particulate matter. Warehousing is a significant risk factor, as warehouses consume significant amounts of electricity, generate packaging waste and can pose a threat to soil and water if hazardous goods are stored. Packaging also affects environmental safety, especially when materials unsuitable for recycling or reuse are used. The energy consumption of logistics processes – transport,

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warehousing, freight and information – increases emissions and dependence on fossil resources. An additional risk is inefficient route organization, which results in unnecessary mileage, increased fuel consumption, and higher emission intensity. Thus, the environmental safety of logistics encompasses the impacts of transport, warehousing, packaging, energy use, and organizational processes, and is achieved through resource-efficient technologies and environmentally friendly planning and optimization models that minimize environmental risks and support the sustainable development of logistics systems.

In this context, the sustainability of logistics systems is considered an integral characteristic, ensuring the efficient movement of material flows with minimal environmental impact and the rational use of natural resources. The theoretical basis of such environmentally friendly logistics is formed by the concepts of «green logistics», «sustainable supply chains», and «low-carbon logistics», which interpret the interaction between logistics processes and the environment in different ways but are united in their aim to enhance environmental safety. The concept of «green logistics» focuses on reducing the negative impact of logistics activities by optimizing routes, reducing packaging waste and implementing energy-efficient solutions [8, p. 64]. The sustainable supply chain approach integrates environmental, economic, and social priorities, introduces circular models of resource movement, and ensures compliance with international standards for sustainable development. The concept of low-carbon logistics aims to reduce greenhouse gas emissions by using alternative fuels, electrifying transport, and optimizing transportation, while accounting for the carbon intensity of flows.

Further development of these approaches is ensured by the implementation of international standards that set requirements for the environmental performance of logistics. In particular, ISO 14001 regulates the environmental management systems of enterprises [19], and ISO 14083 establishes a methodology for calculating and reporting greenhouse gas emissions in transport operations [20]. In the EU, the

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Taxonomy of Sustainable Activities, which defines criteria for the environmental acceptability of logistics processes [21], and the Corporate Sustainability Reporting Directive (CSRD) EU 2022/2464, which obliges the disclosure of data on the environmental consequences of activities, including logistics operations [22]. Assessing the sustainability of logistics systems is impossible without specialized environmental indicators. Key among them is the CO_2 emissions per tonne-kilometre, which reflects the intensity of carbon emissions during the transportation of goods [3, p. 806]. Also important are the fuel efficiency index, which measures energy consumption for logistics operations [2], and the ecological route efficiency index, which accounts for distance, traffic conditions, and emission levels [13, p. 35].

Thus, modern concepts, standards, and indicators form the methodological basis for environmentally friendly logistics, which combines economic efficiency with the rational use of resources and the minimization of negative environmental impact. In this context, it is essential to assess countries' logistics maturity to identify the strengths and weaknesses of their transport and logistics systems and outline directions for their optimisation, taking into account environmental trends. The most common international tool for such an assessment is the Logistics Performance Index (LPI) [23], which integrates indicators of infrastructure quality, operator competence, organisation of international transportation, customs procedures, timeliness of deliveries and the development of cargo tracking systems (fig. 1).

A comparison of the LPI for 2010–2023 indicates significant differences in logistics systems across countries, affecting both their environmental capacity and the potential to optimize supply chains. Singapore and Germany consistently occupy leading positions (4.09–4.30 and 4.11–4.23, respectively), demonstrating a high level of infrastructure, transportation organization, and logistics efficiency, which, at the same time, contributes to reducing the environmental burden. The USA and Japan maintain high scores (3.86–3.99 and 3.90–3.97), indicating technological

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maturity and a developed transport network that creates favorable conditions for the implementation of low-carbon strategies. In contrast, Ukraine has significantly lower LPI values (mainly 2.57–2.74–2.70), which reflect systemic limitations in infrastructure, flow organization, and operator competence. At the same time, such results indicate significant potential to increase the environmental efficiency of logistics by reducing unnecessary mileage, optimizing routes, and reducing energy consumption.

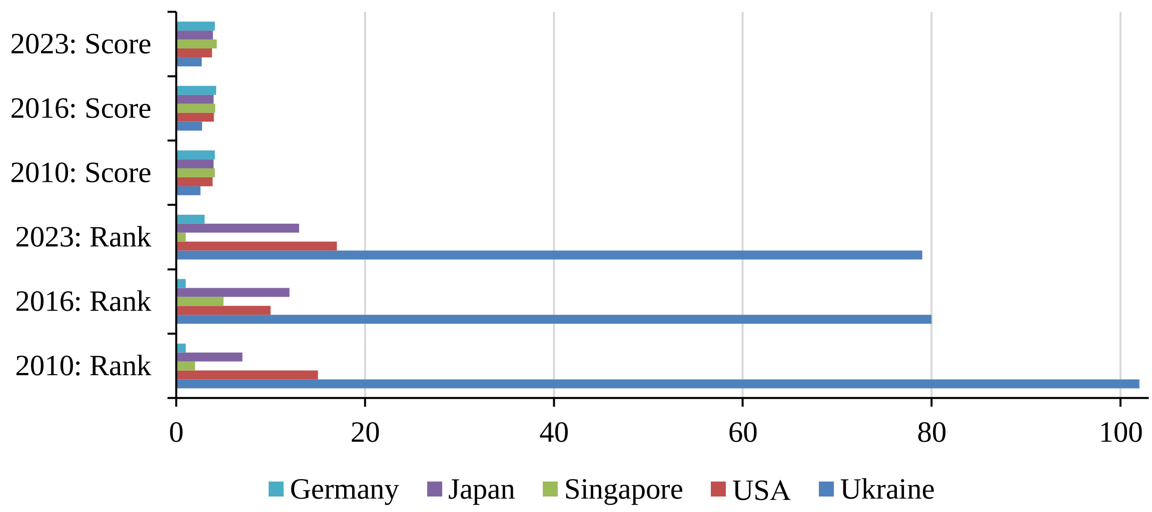

Fig. 1. Comparison of overall LPI indicators for selected countries (2010–2023)

Source: constructed according to [23]

The comparative analysis of overall LPI scores showed significant differences in countries' logistics performance, which directly affects their potential to implement environmentally friendly solutions. However, the integral indicator does not allow for a complete assessment of the structure of logistics capabilities or for identifying the elements that pose the most significant barriers or, conversely, create conditions for increasing the environmental safety of logistics processes. That is why the next stage of the study is the analysis of the component structure of the LPI index, which reflects the quality of customs procedures, the development of infrastructure, the efficiency of international transportation, the professional level of logistics operators, the ability to track cargo and the timeliness of delivery.

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The distinction between these indicators allows us to more clearly identify which structural elements of the logistics system contribute to the rationalization of flows and the reduction of environmental burden, and which, on the contrary, create risks of excessive mileage, delays and inefficient use of transport resources. The summarized results on the key components of logistics performance are presented in table 1.

Table 1

LPI component structure (2023)

Country	LPI total score	Customs procedures	Infrastructure	International transportation	Logistics competence	Timeliness	Tracking and tracing
Singapore	4,3	4,2	4,6	4,0	4,4	4,3	4,4
Finland	4,2	4,0	4,2	4,1	4,2	4,3	4,2
Germany	4,1	3,9	4,3	3,7	4,2	4,1	4,2
Japan	3,9	3,9	4,2	3,3	4,1	4,0	4,0
USA	3,8	3,7	3,9	3,4	3,9	3,8	4,2
China	3,7	3,3	4,0	3,6	3,8	3,7	3,8
Ukraine	2,7	2,4	2,4	2,8	2,6	3,1	2,6

Source: constructed according to [24]

The analysis of the LPI components shows significant heterogeneity in the logistics systems of the studied countries, which determines their differing potential to improve the environmental safety of logistics. Singapore demonstrates the highest and most balanced values - developed infrastructure (4.6), high logistics competence and high-quality tracking and delivery systems (4.3–4.4), which ensures low energy intensity and the possibility of implementing low-carbon technologies. Finland and Germany have similar strong positions due to the maturity of infrastructure and the professionalism of logistics operators (4.2–4.3), which contribute to reducing idle runs and the carbon footprint. Japan and the USA demonstrate high but less balanced scores, particularly due to lower international transport rates (3.3–3.4), reflecting

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institutional barriers and additional energy costs. Ukraine significantly lags in all components of the LPI: weak customs procedures and infrastructure (2.4), insufficient logistics competence (2.6) and moderate timeliness of delivery (3.1). Such a disproportion leads to increased environmental risks: excessive downtime, slow cargo processing, irrational use of transport, and increased emissions per unit of transportation. Therefore, countries with high LPI values have the opportunity to implement low-carbon solutions comprehensively. In contrast, countries with fragmented development need to prioritize improving infrastructure, customs procedures, and professional logistics competence.

At the same time, analyzing logistics capabilities alone does not provide a complete picture of the environmental dimension of logistics. For a real assessment of the level of environmental safety, it is necessary to take into account the actual volumes of greenhouse gas emissions [24], primarily in the transport sector - one of the most carbon-intensive elements of logistics chains. Comparing CO_2 emissions from transport enables us to determine the environmental intensity of logistics systems, trace the relationship between infrastructure development and decarbonization levels, and assess the scale of necessary environmental measures. The summarized indicators for 2010–2022 are presented in fig. 2.

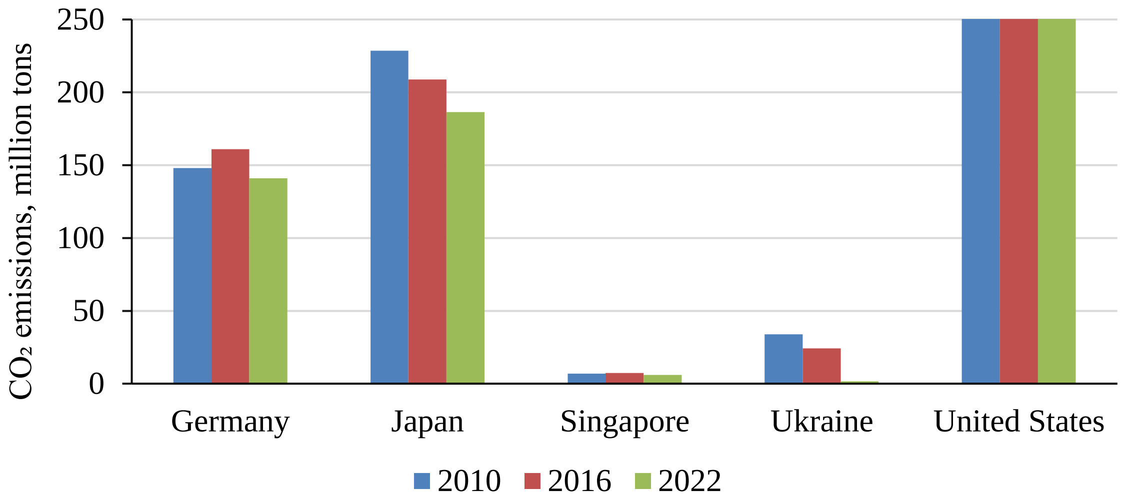

Fig. 2. CO_2 emissions from transport (2010–2022)

Source: constructed according to [24]

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A comparison of CO_2 transport emissions dynamics shows significant differences across countries, reflecting the level of economic activity and the effectiveness of decarbonization. The USA and Japan have the highest emissions; however, Japan is gradually reducing them through technological modernization of its transport sector. In Germany, a decrease is also observed after the 2016 peak, which is associated with infrastructure modernization and EU environmental standards. Singapore has small but stable volumes, which indicates effective management of the transport system. The sharpest drop was recorded in Ukraine – from 33.9 million tons in 2010 to 1.65 million tons in 2022, which is due not to environmental reforms, but to a sharp reduction in transport activity and the destruction of infrastructure as a result of the war. Therefore, the level of environmental safety of logistics is primarily determined by the organization of transport flows. High emissions are often caused not only by technological barriers, but also by inefficient route planning, low transport utilization and long logistics cycles. Therefore, a key direction for increasing environmental sustainability is implementing optimal supply planning to reduce energy and transport losses.

Optimal supply planning is a key tool for reducing the environmental burden of logistics, as the rational organization of flows determines energy consumption, transport efficiency, and greenhouse gas emissions. The planning methodology combines analytical, mathematical, and digital approaches to minimize transport costs, reduce unnecessary transportation, and improve the manageability of supply chains. The basic direction is the modelling of transport flows, including the construction of optimal routes that account for distance, infrastructure load, transport type, and emission levels. The use of shortest-path models, multi-criteria optimization, and logistics cost-minimization algorithms allows you to reduce mileage, downtime, and transportation energy consumption. No less important is the optimization of vehicle loading: rational distribution of weight and volume reduces the number of trips and specific emissions. In combination with cargo consolidation,

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cooperation between shippers and the joint use of transport capacities, a tangible environmental effect is formed.

Inventory management is an essential component of optimal supply planning. Demand forecasting systems and dynamic models for determining order sizes and coordinating delivery schedules make it possible to avoid excess transportation, accelerate inventory turnover, and reduce the need for energy-intensive emergency deliveries. Digitalization significantly expands the possibilities for optimization: supply chain management systems, real-time cargo tracking platforms, and predictive analytics enable adaptive planning models that account for changes in demand, traffic conditions, weather, and environmental indicators. It increases planning accuracy and reduces the risks of supply disruptions, ensuring minimal energy consumption of logistics operations. Modern approaches also include stochastic optimization, which allows taking into account uncertainty - fluctuations in demand, changes in transport availability and other external factors. Risk-based optimization ensures the selection of more sustainable routes and minimizes environmental load even under shock conditions.

Thus, the comprehensive application of optimal planning methods forms the basis for environmentally friendly logistics: it reduces energy consumption, CO_2 emissions, and increases the efficiency of transport and information resources. In this context, supply optimization is not only a tool for economic efficiency but also an essential factor in implementing decarbonization strategies. Given the results, it is advisable to develop an integrated model that combines monitoring, planning, and optimisation mechanisms and enables the assessment of the environmental impact of logistics solutions (fig. 3).

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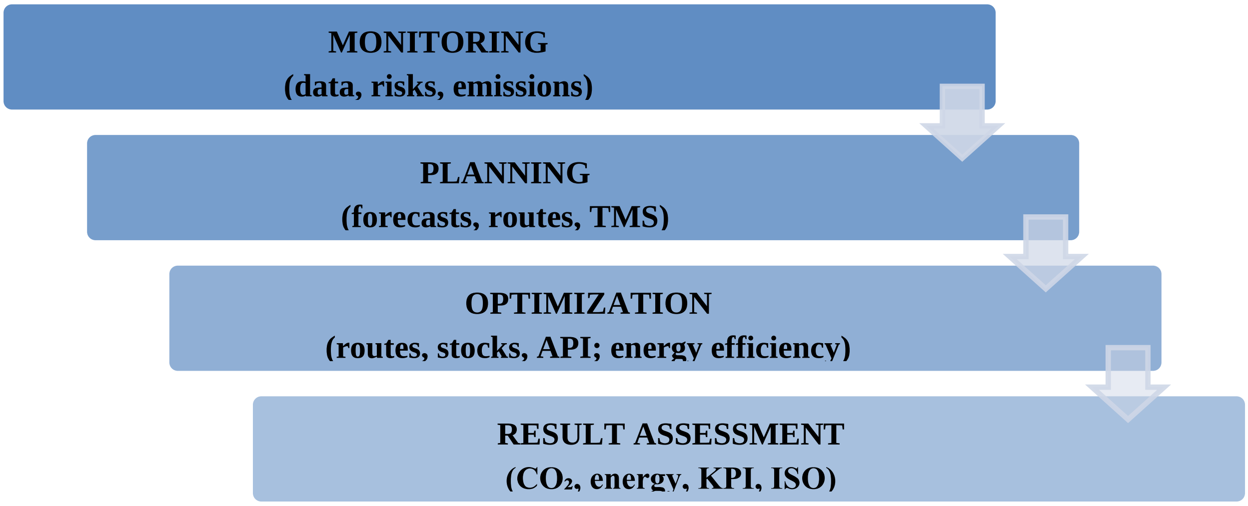

Fig. 3. Model for improving the environmental safety of logistics processes

Source: developed by the author

The presented model for increasing the environmental safety of logistics processes is based on four interconnected blocks that form a closed management cycle. The first block – monitoring – provides continuous collection of information on emissions, transport flows, resource intensity and environmental risks. Based on these data, the second block – planning is established, which includes forecasting transportation needs, forming optimal routes, coordinating supply volumes and choosing the most resource-efficient logistics solutions. The third block – optimisation – involves minimizing energy consumption, reducing empty runs, rationalizing transport loading, and using innovative digital tools to increase the efficiency of flows. The fourth block – assessing environmental results – provides measurement of the achieved effect against key indicators, analysis of compliance with sustainable development standards, and the formulation of recommendations for further improvement. The coordinated operation of these blocks creates an adaptive system that simultaneously improves logistics operations and reduces their environmental impact.

For the full implementation of the proposed model, a toolkit is necessary that enables the identification and ranking of key environmental threats in logistics processes. That is why a logical addition to the model is a risk assessment matrix (table 2), which identifies potential environmental load sources and indicates the direction of their neutralization.

Table 2

Matrix for assessing the environmental safety of logistics processes

Source of environmental risk	**Nature of impact**	**Risk level**	**Neutralization mechanisms**
Transportation			
CO_2, NO_x, SO_2 emissions; empty runs; low loading	Increased carbon footprint, air quality degradation	High	Route optimization, fleet electrification, cargo consolidation
Warehousing			
Energy consumption, refrigerant losses, and inefficient insulation	Increased energy consumption, HFC emissions	Medium	RES, energy-efficient lighting and cooling systems, automation
Packaging			
Excessive use of materials, waste	Generation of significant MSW	Medium	Recycled materials, circular solutions, and elimination of excess packaging
Customs and logistics operations			
Transportation delays, border delays	Accumulation of emissions due to engine idling	Medium–high	Digitalization of procedures, electronic queues, and pre-clearance
Information flows			
Insufficient data for planning, inconsistent schedules	Inefficient planning, unnecessary trips	Medium	TMS/WMS, IoT tracking, digital data platforms
International transportation			
Incoherence in multimodal schemes	Duplication of routes, increased distances	High	Carrier coordination, optimal intermodal hubs
Reverse logistics			
Low level of waste recycling	Waste accumulation, increased CO_2	Medium	Reverse logistics, recycling, material reuse

Source: constructed by the author

The proposed matrix for assessing the environmental safety risks of logistics processes complements the model's structure. It serves as a practical tool for a comprehensive quantitative and qualitative analysis of environmental threats. It allows you to systematically determine which logistics operations generate the primary sources of environmental load, assess their criticality, and outline the most effective mechanisms to neutralize the risks.

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Conclusions. The study enabled substantiation of the methodological principles for increasing the environmental safety of logistics processes through optimal supply planning and assessment of the structural characteristics of logistics systems. Analysis of international logistics performance indices showed significant differences between countries in terms of infrastructure development, operator competence, and the efficiency of transport flows, which determine their ability to implement environmentally friendly solutions. A comparison of the dynamics of transport CO_2 emissions confirmed that the environmental intensity of logistics depends not only on the technological level of transport, but also on the rational organization of supply chains and the efficiency of resource use. Based on theoretical provisions and analytical results, an integrated model of environmentally safe logistics has been developed, combining monitoring, planning, optimisation, and assessment of environmental outcomes. The model provides systematic management of emissions and energy efficiency, and creates a practical basis for implementing low-carbon technologies. Its addition to a matrix of environmental risks increases the model's practical value, enabling it to identify critical sources of threat and set management priorities. The results obtained confirm that optimal supply planning is an effective tool for reducing emissions, reducing energy consumption and forming environmentally balanced logistics chains. The proposed methodological approaches ensure the transition to more sustainable, resource-efficient, and environmentally safe supply systems that align with modern trends in logistics development and the requirements of sustainable development. Prospects for further research include developing tools for quantitative assessment of the environmental effects of supply optimisation and modelling low-carbon logistics scenarios that take into account digital technologies and changes in global transport flows.

 ISSN: 2786-9431

References

1. Hryniv N. T., Andrukhiv V. A. Green logistics as a global trend development of business processes. *Scientific Notes of Lviv University of Business and Law*. 2023. № 39. P. 51-57. URL: https://nzlubp.org.ua/index.php/journal/article/view/960 [in Ukrainian].

2. Lu M., Xie R., Chen P., Zou Y., Tang J. Green transportation and logistics performance: an improved composite index. *Sustainability*. 2019. Vol. 11, №. 10. Article 2976. DOI: https://doi.org/10.3390/su11102976.

3. Dubisz D., Golińska-Dawson P., Koliński A. Measuring CO_2 emissions level for more sustainable distribution in a supply chain. *Engineering and Applied Science Research*. 2022. Vol. 49, № 6. P. 804–810. DOI: https://doi.org/10.14456/easr.2022.78.

4. Borchardt M., Pereira G., Milan G., Pereira E., Lima L., Bianchi R., Scavarda do Carmo A. Are sustainable supply chains managing Scope 3 emissions? A systematic literature review. *Sustainability*. 2025. Vol. 17, № 13. Article 6066. DOI: https://doi.org/10.3390/su17136066.

5. Ma Zh., Yang X., Miao R., Yue Y. Sustainable development of low-carbon supply chain economy based on the Internet of Things and environmental responsibility. *Economics*. 2024. Vol. 18, № 1. Article 20220099. DOI: https://doi.org/10.1515/econ-2022-0099.

6. Verma P., Mishra V. K. Optimizing the sustainability in the supply chain for imperfect deteriorating items under remanufacturing and carbon emission regulation. *Journal of Systems Science and Systems Engineering*. 2025. DOI: https://doi.org/10.1007/s11518-025-5644-1.

7. Routroy S., Sahu P., Chhetri P. Editorial: decarbonizing logistics and supply chains: sustainable innovation for global impact. *Journal of International Logistics and Trade*. 2025. Vol. 23, № 1. P. 2–6. DOI: https://doi.org/10.1108/JILT-03-2025-107.

 ISSN: 2786-9431

8. Reznik N., Marynina O. «Green» logistics in the business of logistics transportation: prospects and features of the development of «green» logistics in business for Ukraine. *Ukrainian Journal of Applied Economics and Technology*. 2024. Vol. 9, № 1. P. 62–66. DOI: https://doi.org/10.36887/2415-8453-2024-1-10 [in Ukrainian].

9. Hatylo V. P. Sustainable logistics management: implementing ESG strategies into logistics processes. *Journal of Economic Reforms*. 2025. № 2(58). P. 144–153. URL: http://nbuv.gov.ua/UJRN/Cher_2025_2_19 [in Ukrainian].

10. Ilina A. O. Investments as a tool for accumulating human capital. *Science and Technology Today. Series: Economy*. 2025. № 1(42). P. 305–320. DOI: https://doi.org/10.52058/2786-6025-2025-1(42)-305-320 [in Ukrainian].

11. Korobkova O. M., Korobkova Z. S. The role of customs logistics in international transportation. *Scientific Notes of the V. I. Vernadsky TNU. Series: Technical Sciences*. 2024. Vol. 35(74), № 3. P. 177–182. DOI: https://doi.org/10.32782/2663-5941/2024.3.2/27 [in Ukrainian].

12. Kaptosv L. RESTful API design for geospatial logistics platforms using TypeScript and Laravel. *Journal of Information, Technology and Policy*. 2025. P. 1–13. DOI: https://doi.org/10.62836/jitp.2025.515.

13. Korostin O. Optimization of maritime transport routes using artificial intelligence: analysis of opportunities and challenges. *Computer-Integrated Technologies Education Science Production*. 2024. № 56. P. 31–38. DOI: https://doi.org/10.36910/6775-2524-0560-2024-56-03[in Ukrainian].

14. Kantsedal N., Leha O., Morozov Y. Digitalization of logistics: new technologies to improve management and optimization. *Economic scope*. 2025. № 199. P. 45–51. DOI: https://doi.org/10.30838/EP.199.45-51 [in Ukrainian].

15. Li S., Sun T. Research on the impact of green logistics on carbon emission intensity of transportation industry. *Global NEST Journal*. 2024. Vol. 26, № 6. Article 05943. URL: https://journal.gnest.org/system/files/2024-

08/gnest_05943_final.pdf (date access: 20.05.2025).

16. Jia F., Pan T., He Q., Zhang T., Chen L. Supply chain design: implications for sustainability. *International Journal of Logistics Research and Applications*. 2024. Vol. 28, № 6. P. 581–604. DOI: https://doi.org/10.1080/13675567.2024.2313058.

17. Ivanova M., Sannikova S., Varyanichenko O., Kharin S., Boichenko M., Riabyk H. Statistical methods for managing risks in planning foreign economic and logistics activities for sustainable development of the enterprise. *Financial and Credit Activity Problems of Theory and Practice*. 2024. Vol. 3, № 56. P. 241–256. DOI: https://doi.org/10.55643/fcaptp.3.56.2024.4380.

18. Vajdanych T. V., Kulchytska E. A., Nalyvaiko N. Y. Integration of environmental logistics into modern systems of operations management and sales administration. *Efficiency of Public Administration*. 2025. № 1(82/83). P. 125–131. DOI: https://doi.org/10.36930/508216 [in Ukrainian] .

19. ISO 14001:2015. *ISO*. URL: https://www.iso.org/standard/60857.html (date access: 20.05.2025).

20. ISO 14083:2023. *ISO*. URL: https://www.iso.org/standard/78864.html (date access: 20.05.2025).

21. EU taxonomy for sustainable activities. *European Commission*. URL: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en (date access: 20.05.2025).

22. Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. *EUR-Lex*. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464 (date access: 20.05.2025).

23. Logistics Performance Index (LPI). *World Bank Group*. URL: https://databank.worldbank.org/source/logistics-performance-index-%28lpi%29#

(date access: 20.06.2025).

24. CO_2 emissions from transport. *Our World in Data*. URL: https://ourworldindata.org/grapher/co2-emissions-transport?tab=line&time=earliest..2022&country=UKR~USA~DEU~SGP~JPN&mapSelect=UKR~USA~DEU~SGP~JPN (date access: 20.05.2025).