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# TRANSFORMING PHARMACEUTICAL SUPPLY CHAINS THROUGH GREEN LOGISTICS

## ТРАНСФОРМАЦІЯ ФАРМАЦЕВТИЧНИХ ЛАНЦЮГІВ ПОСТАЧАННЯ НА ЗАСАДАХ ЗЕЛЕНОЇ ЛОГІСТИКИ

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Pharmaceutical supply chains occupy a critical position in healthcare, operating under stringent regulatory requirements and elevated risks. Growing attention has been paid to green logistics as a sustainability framework, yet its adoption in Ukraine's pharmaceutical sector remains fragmented and lacks systematic coherence. This study examines supply chain practices of JSC "Farmak", BaDM LLC, Optima-Pharm LLC, and Venta Ltd, focusing on energy efficiency, waste reduction, and digitalisation. Green logistics elements are concentrated at the manufacturing level, where ESG principles are actively pursued. Distributors focus on operational efficiency including route optimization, warehouse automation, and cold chain management, which indirectly improves environmental performance but is not explicitly framed within green logistics strategies. Digital technologies and risk management are key enablers of supply chain resilience.

**Keywords:** pharmaceutical supply chains, green logistics, supply chain resilience, martial law, risk management, logistics digitalization, cold chain, decarbonization, sustainable development, OECD, ESG, GDP.

У статті досліджено теоретико-методичні та прикладні аспекти трансформації фармацевтичних ланцюгів постачання на засадах зеленої логістики в умовах воєнного стану в Україні. Обґрунтовано, що фармацевтичні ланцюги постачання є критично важливим елементом національної безпеки та системи охорони здоров'я, оскільки забезпечують безперервний доступ населення до лікарських засобів. Визначено, що традиційні підходи до управління ланцюгами постачання в умовах військових ризиків втрачають ефективність через порушення логістичної інфраструктури, нестабільність транспортних маршрутів, енергетичні обмеження та зміну структури попиту. Проаналізовано сучасні наукові підходи до формування стійкості ланцюгів постачання, зокрема ризик-орієнтоване управління, цифровізацію логістичних процесів та впровадження адаптивних стратегій. Встановлено, що існуючі моделі недостатньо враховують специфіку фармацевтичної галузі та ризики воєнного часу, зокрема перебої у постачанні активних фармацевтичних інгредієнтів, порушення холодового ланцюга та логістичні затримки. Запропоновано авторський підхід до визначення стійкості як інтегрованої здатності системи прогнозувати, запобігати, адаптуватися та відновлювати функціонування в умовах невизначеності. Особливу увагу приділено концепції зеленої логістики як інструменту забезпечення екологічної сталості фармацевтичних ланцюгів постачання. Визначено ключові принципи її реалізації, зокрема екологічну безпеку, оцінювання життєвого циклу, енергоефективність та циркулярність. Доведено, що впровадження зеленої логістики сприяє зниженню викидів CO<sub>2</sub>, оптимізації використання ресурсів, скороченню відходів та підвищенню ефективності логістичних процесів. Систематизовано підходи до впровадження зеленої логістики (технологічний, процесно-організаційний та цифровий), обґрунтовано їх взаємодоповнюваність та доцільність інтегрованого застосування. Розроблено стохастичну багатокритеріальну оптимізаційну модель управління фармацевтичними ланцюгами постачання, що враховує економічні, екологічні та ризик-орієнтовані параметри в умовах невизначеності. Практичне значення дослідження полягає у формуванні науково обґрунтованих



рекомендацій щодо підвищення стійкості та екологічної ефективності фармацевтичних ланцюгів постачання шляхом диверсифікації постачальників, розвитку альтернативних логістичних маршрутів, впровадження цифрового моніторингу та інтеграції принципів сталого розвитку.

**Ключові слова:** фармацевтичні ланцюги постачання, зелена логістика, стійкість ланцюгів постачання, воєнний стан, ризик-менеджмент, цифровізація логістики, холододовий ланцюг, декарбонізація, сталий розвиток, OECF, ESG, GDP.

**Statement of the problem.** The transformation of pharmaceutical supply chains under current global challenges has become a critical issue, particularly in the context of environmental sustainability, increasing regulatory pressure, and the need to ensure uninterrupted access to medicines. Traditional logistics models in the pharmaceutical sector are predominantly focused on efficiency, cost minimization, and service level optimization, often neglecting environmental impacts such as carbon emissions, excessive packaging, and waste generation. At the same time, the growing importance of sustainable development principles and the transition toward green economy models necessitate a fundamental rethinking of supply chain management approaches. The concept of green logistics offers significant potential for reducing the ecological footprint of pharmaceutical distribution while maintaining high standards of quality, safety, and reliability.

However, despite the increasing attention to sustainability, there remains a lack of comprehensive methodological approaches to the transformation of pharmaceutical supply chains based on green logistics principles. In particular, insufficient integration of environmental criteria into decision-making processes, limited digitalization, and the absence of adaptive management mechanisms under conditions of uncertainty (including wartime disruptions and global crises) hinder the effective implementation of green practices.

Therefore, the problem lies in the need to develop and substantiate scientific and methodological approaches to the transformation of pharmaceutical supply chains that ensure their sustainability, adaptability, and environmental responsibility through the integration of green logistics principles.

**Analysis of recent research and publications.** Recent studies consistently highlight that green logistics is becoming a key direction in transforming pharmaceutical supply chains, as it integrates environmental sustainability with operational efficiency and supply chain resilience. Foreign researchers have made a significant contribution to this

field. Tetteh, Kwateng, and Mensah, in their bibliometric and systematic review, identify key research trajectories in green logistics, emphasizing the growing role of sustainability-oriented models and outlining future research directions in this area [1]. Jefimovaitė and Vienažindienė demonstrate that green logistics significantly improves both environmental and economic performance of organizations [2].

Agarwal and Goel focus on the integration of green logistics and green transportation into supply chains, emphasizing reduced environmental impact and improved resource efficiency through digital technologies and sustainable practices, while also identifying barriers such as high costs, regulatory constraints, and technological limitations [3]. The bibliometric analysis by Nikseresht, Golmohammadi, and Zandieh highlights the growing importance of circular economy principles, reverse logistics, and remanufacturing in modern green logistics systems [4]. A systematic literature review further structures knowledge into key domains, including planning, management, technologies, and optimization approaches [5].

Among Ukrainian researchers, Nadiia Reznik and Olena Marynina analyze green logistics principles and their implementation in Ukraine, emphasizing the integration of economic, social, and environmental components for resource efficiency [6]. Yna Salo examines institutional and infrastructural barriers to green logistics development in Ukraine [7].

Further studies by Lesia Taraievska and Iryna Haliuk focus on transport optimization and energy-efficient logistics solutions [8]. Olha Kuchkova and Yakov Olefirenko propose innovative approaches to improving environmental efficiency through logistics optimization [9]. O. Bondarenko and O. Bozhko emphasize the strategic role of green logistics in balancing economic, environmental, and social goals [10]. Halyna Kupalova, Nataliia Goncharenko, and Mariia Dudnik focus on modernization of logistics systems through environmentally oriented technologies [11].

Overall, the literature confirms the growing importance of green logistics in pharmaceutical

supply chains. However, gaps remain in measuring resilience, integrating digital technologies, and developing comprehensive implementation frameworks for the pharmaceutical sector.

**Highlighting previously unresolved parts of the overall problem.** The conducted analysis of scientific sources demonstrates significant progress in the development of the green logistics concept, particularly regarding decarbonization, digitalization, the implementation of circular approaches, and the enhancement of energy efficiency in logistics systems. At the same time, despite a substantial body of theoretical and applied research, a number of scientific and practical problems remain unresolved.

Specifically, there is insufficient research on adapting green logistics principles to the specific requirements of individual industries, such as pharmaceuticals, which is characterized by stringent demands for quality, safety, temperature control, and supply continuity. Furthermore, studies focusing on the integration of environmental criteria into managerial decision-making processes under conditions of uncertainty and global crises remain limited. Particular attention is required for the challenges of implementing digital technologies in green logistics within resource-constrained environments, as well as the formation of effective mechanisms for assessing the environmental performance of logistics systems based on the full product life cycle.

Additionally, methodological approaches to the comprehensive transformation of supply chains based on sustainable development principles, which account for the interplay between economic, environmental, and social factors - remain underdeveloped. In this regard, there is an objective necessity for further scientific research aimed at developing theoretical and methodological foundations as well as practical tools for the transformation of supply chains based on green logistics principles, taking into account sectoral specificities, modern technological solutions, and global challenges.

**Formation of the objectives of the article (task statement).** Under martial law in Ukraine, pharmaceutical supply chains are undergoing significant changes due to disruptions to transport infrastructure, interruptions in the supply of raw materials, rising logistics costs and increased risks to the continuity of the supply of medicines to the population. At the same time, the environmental aspect of logistics systems is becoming increasingly important, necessitating a shift towards sustainable management models.

However, existing approaches to organising pharmaceutical supply chains in crisis situations are predominantly focused on ensuring supply continuity and do not sufficiently account for environmental aspects, the principles of green logistics, and decarbonisation tools. This limits the possibilities of achieving a balance between sustainability, efficiency and environmental safety in logistics processes.

In this regard, the aim of this article is to substantiate the scientific and methodological foundations for the transformation of pharmaceutical supply chains based on the principles of green logistics under martial law. To achieve this objective, the following tasks are addressed:

- to investigate the specific features of pharmaceutical supply chain operations under conditions of military risks;
- to identify the key factors undermining the sustainability and environmental efficiency of logistics processes;
- to justify the role of green logistics as a tool for enhancing the adaptability and resilience of supply chains;
- to develop practical recommendations for transforming pharmaceutical supply chains under martial law, taking into account the principles of sustainable development.

**Summary of the main research material.** In modern conditions, pharmaceutical supply chains play a critical role in ensuring public health and national security. Under martial law, these systems face unprecedented disruptions due to infrastructure damage, interruptions in transport routes, increased security risks, and instability of logistics operations. Such challenges significantly affect the availability and continuity of supply of essential medicines, which becomes particularly critical in conditions of humanitarian crisis.

At the same time, global trends in sustainable development require the integration of environmental principles into logistics and supply chain management. The concept of green logistics is becoming increasingly important as a tool for reducing the negative environmental impact of logistics processes while maintaining their efficiency and reliability. In the context of martial law, the combination of resilience and environmental sustainability becomes a key requirement for the effective functioning of pharmaceutical supply chains.

Pharmaceutical supply chains are among the most complex and resource-intensive due to the need to ensure: temperature control (the cold

chain), high quality standards, global access to medicines. At the same time, they are a significant source of greenhouse gas emissions. According to the OECD (2025), 79% of emissions from healthcare systems are attributable to supply chains, with pharmaceutical and medical products generating approximately 25% of all emissions. This highlights the critical need to transform logistics processes [12].

Green Logistics in the pharmaceutical sector is a comprehensive system for managing flows of medicinal products and information, aimed at minimizing environmental impact while maintaining uncompromising product quality and safety in accordance with GxP standards.

Fundamental principles Green Logistics:

- Principle of ecological safety (Bio-Safety First): Any “green” solution must not create risks to the stability of the active substance of the pharmaceutical product.

- Life Cycle Assessment principle (LCA): Assessment of environmental impact from the production of the active substance to the disposal of expired medicines or packaging.

- Principle of energy-efficient distribution: Maximum utilization of resources while ensuring temperature control.

- Principle of circularity (3R: Reduce, Reuse, Recycle): Reduction of secondary packaging volumes, reuse of thermal containers, and recycling of plastic medical waste.

Unlike the consumer goods retail sector, pharmaceutical logistics is governed by GDP (Good Distribution Practice) standards. The main environmental challenges facing the industry include:

- CO<sub>2</sub> emissions resulting from the need to maintain temperature control (the cold chain) during transport.

- Excessive use of packaging materials (insulated containers, single-use temperature indicators).

- Disposal of expired products, which requires special decontamination methods that are often energy-intensive.

Indeed, the pharmaceutical industry generates 55% more greenhouse gas emissions per unit of revenue than the automotive industry. The main source is ‘cold chain’ logistics, where maintaining the temperature (+2..+8°C or -20°C) requires significant energy consumption.

The implementation of green logistics principles enables cost optimization. Below is a comparison of traditional and “green” logistics models based on average market indicators (according to research data for 2024–2025).

Green logistics in pharmaceutical supply chains delivers significant improvements in key performance indicators compared to the traditional model (table 1). The proportion of packaging waste is reduced to 4–6% (–70%), the use of passive systems increases to 65%, and reverse logistics to over 40%, thereby minimising losses. Specific CO<sub>2</sub> emissions are reduced by approximately 35% (from 120 to 78 kg per 1,000 units of product), confirming the high environmental efficiency of the green model and its strategic viability [1; 13; 14; 15].

We will analyse approaches to implementing ‘green’ logistics in pharmaceutical supply chains, which form a comprehensive management system aimed at combining environmental efficiency, operational efficiency and digital transformation (table 2).

An analysis of approaches to implementing green logistics in pharmaceutical supply chains demonstrates their complementary nature and systemic character. The technological approach delivers a direct environmental benefit by reducing emissions and improving energy efficiency, but requires significant investment. The process-organisational approach aims to optimise processes, reduce costs and increase flexibility, but depends on the level of coordination among participants. The digital

Table 1

**Comparative characteristics of logistics models in the pharmaceutical sector**

Indicator	Traditional logistics	Green logistics	Forecast effect
Share of packaging waste (%)	15–22	4–6	Reduction by 70%
Use of passive systems (%)	10	65	Reduction of energy costs
Reverse logistics level (%)	< 5	> 40	Loss minimization
Specific CO <sub>2</sub> emissions (kg per 1000 units)	120	78	Reduction by 35%

Source: compiled by the author based on [1; 13; 14; 15]

Table 2

**Comparative characteristics of approaches to implementing green logistics in pharmaceutical supply chains**

<b>Approach</b>	<b>Main Toolkit</b>	<b>Benefits for Pharmacy</b>	<b>Risks / Constraints</b>
Technological	Use of electric and hybrid vehicles; application of passive and active thermal containers; implementation of IoT sensors for temperature control; use of solar panels at warehouses; energy-efficient refrigeration systems.	Direct and rapid reduction of CO <sub>2</sub> emissions; ensuring "cold chain" stability; increasing energy efficiency; reducing product losses due to temperature excursions.	High capital expenditures (CAPEX); long payback periods; dependence on energy infrastructure; limited availability of technologies in crisis conditions.
Process-Organizational	Delivery route optimization; cargo consolidation; implementation of ISO 14001 standards; Lean and Leagile approaches; implementation of Just-in-Time principles; inventory management using ABC/XYZ models; warehousing optimization.	Improving the overall efficiency of logistics processes; reducing logistics costs; shortening delivery times; reducing waste volumes; increasing the flexibility and adaptability of supply chains.	Complexity of coordination between supply chain participants; need for a high level of managerial maturity; risks of supply disruptions in case of synchronization failure; necessity of changing organizational culture.
Digital (Smart-Green)	Use of Artificial Intelligence (AI) for demand forecasting; Big Data analytics; Blockchain for traceability of reverse flows; IoT for monitoring storage conditions; digital supply chain management platforms; Digital Twin systems.	Minimizing write-offs and losses through accurate forecasting; increasing transparency and traceability; reducing the environmental footprint; improving risk management; enhancing the quality of managerial decision-making.	High costs of digital infrastructure and software; cybersecurity risks and data protection issues; shortage of qualified specialists (digital gap); integration challenges with legacy systems.

*Source: compiled by the author based on [16-19]*

(Smart-Green) approach increases transparency and forecasting accuracy whilst reducing losses, but requires a well-developed IT infrastructure.

We will provide an assessment of current sustainability practices at leading pharmaceutical companies in Ukraine and their alignment with the principles of green logistics, based on publicly available data (table 3).

The table presents a comparative qualitative assessment of sustainability practices and their alignment with green logistics principles across four pharmaceutical companies in Ukraine, with different levels of validity based on available data (High, Medium, Low). Farmak JSC demonstrates the highest level of integration of sustainability practices, including ESG auditing, energy efficiency, and waste reduction measures. These actions directly correspond to green logistics principles such as decarbonization and circular economy approaches, supported by high data validity due to official ESG reporting.

BaDM LLC shows a medium level of alignment through GDP certification, logistics information systems, and infrastructure development. These practices contribute indirectly to environmental improvements via process optimization, although the absence of ESG reporting limits transparency. Optima-Pharm LLC also has a medium level of alignment, focusing on warehouse automation, cold chain management, and infrastructure recovery. These measures improve logistics efficiency and reduce losses, but their environmental impact is indirect and not part of a formal ESG strategy.

The analysis of Darnytsia Pharmaceutical Company and Zhytomyr Pharmaceutical Factory reveals significant differences in the level of integration of green logistics and sustainability principles. In particular, Darnytsia Pharmaceutical Company demonstrates a systematic approach to environmental practices, including energy efficiency measures,

Table 3

**Assessment of sustainability practices and their alignment with green logistics principles at pharmaceutical companies in Ukraine**

Company	Officially Confirmed Practices (2024–2026)	Interpretation for Green Logistics	Level of Validity
Farmak JSC (manufacturer)	Implementation of sustainability policy; ESG audit (2025); energy efficiency and waste reduction measures; introduction of energy-saving technologies	Elements of decarbonization, energy efficiency, and circularity (Circular Economy) in supply chains	High (based on official ESG reporting)
BaDM LLC (distributor)	GDP certification; use of logistics management information systems; development of logistics infrastructure	Optimization of logistics processes and resources (indirect reduction of environmental impact)	Medium (no ESG reporting available)
Optima-Pharm LLC (distributor)	Warehouse logistics automation; cold chain management; infrastructure recovery	Reduction of product losses and improvement of logistics efficiency (indirect environmental effect),	Medium
PJSC Darnytsia Pharmaceutical Company	Implementation of sustainability initiatives; energy efficiency measures; environmental protection programs; inclusion in sustainability rankings (Forbes)	Direct implementation of green practices: energy efficiency, environmental management, and elements of sustainable supply chain development	High (based on official corporate disclosures and sustainability recognition)
LTD DKP Pharmaceutical factory	Compliance with GMP standards; modernization of production facilities; quality control systems; gradual technological upgrading	Indirect contribution to green logistics through reduction of production losses, improved resource efficiency, and quality assurance	Medium–Low (limited public sustainability reporting)

Source: compiled by the author based on [20-23]

environmental management initiatives, and participation in sustainability rankings. This indicates a high level of integration of green logistics into its supply chain.

In contrast, Zhytomyr Pharmaceutical Factory primarily focuses on GMP compliance and production modernization, which contribute to operational efficiency and waste reduction but lack formalized ESG or environmental strategies. Therefore, its contribution to green logistics is indirect and can be assessed as medium – low.

Overall, the analysis reveals uneven implementation of green logistics principles in the pharmaceutical supply chain in Ukraine. The manufacturer exhibits a systematic and transparent approach, while distributors mainly achieve environmental benefits indirectly through efficiency improvements. This highlights the need for wider ESG adoption and improved transparency across the sector.

Thus, the most effective approach is a combined model that integrates the advantages of all approaches. Under martial law, a phased implementation is advisable, prioritising process-organisational and digital solutions as they are more adaptable and less costly.

We have proposed a stochastic multi-criteria optimisation model for the management of pharmaceutical supply chains, which formalises the decision-making process under conditions of uncertainty and risk. The model has been developed to ensure that economic, environmental and risk-oriented factors are taken into account in a balanced manner when selecting optimal management decisions.

The model is formulated as a problem [24]:

$$\min_{X \in x} Z(X)$$

$$Z(X) = E\xi [C(X, \xi) + \alpha Ec(X, \xi) + \beta R(X, \xi)],$$

Control Variables X.  $X \in x$  represents a set of management decisions, specifically: supply

volumes, inventory levels, delivery routes, and supplier selection.  $X$  is the set of feasible solutions that defines all constraints: resource, technological, and logistical.

2. Random Factors  $\xi$ . These factors reflect environmental uncertainty: demand fluctuations, supply disruptions, military, economic, and other risks, characterized by a specific probability distribution  $P(\xi)$ .

3. Components of the Objective Function

-  $C(X, \xi)$  – costs (logistical, production, and operational);

-  $Ec(X, \xi)$  – environmental impact (CO<sub>2</sub> emissions, resource consumption)

-  $R(X, \xi)$  – risk (probability of losses or expected losses).

4. Weighting Coefficients  $\alpha$ ,  $\beta$ . These coefficients determine the relative importance of the criteria: the environmental aspect and risk, respectively. They enable a balanced trade-off between economic efficiency, environmental sustainability, and risk mitigation.

The proposed stochastic optimisation model has significant practical relevance for the pharmaceutical market, as it enables the formalisation of decision-making processes under conditions of high uncertainty, which is a characteristic feature of this industry. The pharmaceutical supply chain operates under the influence of a significant number of random factors  $\xi$ , including fluctuations in demand for medicines, supply disruptions, regulatory changes, geopolitical risks and logistical constraints. In this context, the model accounts for the stochastic nature of the environment through mathematical expectation, which allows for the assessment not of individual scenarios, but of the average outcome of the system's operation.

The key components of the objective function have a direct impact on the pharmaceutical market. In particular, the cost function  $C(X, \xi)$  includes costs for the procurement of medicines, their storage taking into account temperature regimes, transportation, as well as costs associated with regulatory requirements. The environmental component  $Ec(X, \xi)$  reflects the impact of pharmaceutical activities on the environment, including the disposal of medicines, the use of packaging, and the carbon footprint of logistics operations, which is becoming increasingly relevant in the context of ESG requirements. Risk component  $R(X, \xi)$  covers aspects such as the risk of shortages of essential medicines, the risk of product spoilage due to breaches of storage conditions, as well as

financial and operational risks associated with supply instability.

We propose the use of this model as a tool for the integrated management of pharmaceutical supply chains in conditions of uncertainty, ensuring the alignment of economic, environmental and risk-oriented objectives. We have also demonstrated that the use of weighting coefficients allows the model to be adapted to the strategic priorities of pharmaceutical companies and the requirements of the regulatory environment.

The weighting coefficients  $\alpha$  and  $\beta$  in the model are of particular importance for the pharmaceutical market, as they allow management decisions to be adapted to healthcare priorities. For example, increasing the weight of the risk component may be justified to ensure uninterrupted access to critically important medicines, whilst an emphasis on the environmental component aligns with contemporary requirements for the sustainable development of the pharmaceutical industry. By varying the coefficient  $\beta$  (risk), the model transforms from an operational management tool into a strategic planning tool for national security in the field of healthcare

Thus, the practical significance of the model lies in ensuring the effective management of pharmaceutical supply chains by simultaneously minimising costs, reducing environmental impact and managing risks in conditions of uncertainty. This contributes to enhancing the resilience of the medicines supply system, ensuring their availability to the public and maintaining an appropriate level of quality in pharmaceutical products, which is critically important in the current operating environment of the sector.

**Conclusions.** The study confirmed that the transformation of pharmaceutical supply chains based on green logistics is a prerequisite for ensuring their sustainability and environmental efficiency, especially under martial law. It has been established that pharmaceutical logistics is characterized by a high level of complexity, significant CO<sub>2</sub> emissions, and the need for a cold chain, which underscores the importance of implementing energy-efficient and resource-saving solutions.

An analysis of scientific sources has shown that the greatest effect is achieved through a comprehensive combination of technological, process-organizational, and digital approaches to green logistics. At the same time, their integration contributes to reducing the environmental impact, optimizing costs, and increasing the

sustainability of supply chains. It has been found that the implementation of green logistics principles allows for a significant reduction in waste, a decrease in emissions, and an increase in resource efficiency; however, the level of their application in Ukraine is uneven. Manufacturers demonstrate a higher level of ESG integration compared to distributors, indicating a need for further development of environmentally oriented practices. The proposed stochastic multi-criteria management model ensures that economic, environmental, and risk factors are taken into

account under conditions of uncertainty, which improves the effectiveness of managerial decision-making in pharmaceutical supply chains.

Further research should focus on adapting green logistics models to the specific characteristics of the pharmaceutical industry, developing methods for assessing the resilience of supply chains, integrating digital technologies, refining ESG approaches, and developing management tools for dealing with crises and military risks.

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