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LOGISTICS INNOVATIONS AS A FACTOR IN INCREASING ENTERPRISE COMPETITIVENESS IN THE EU BIOMATERIALS MARKET

ЛОГІСТИЧНІ ІННОВАЦІЇ ЯК ЧИННИК ПІДВИЩЕННЯ КОНКУРЕНТОСПРОМОЖНОСТІ ПІДПРИЄМСТВ НА РИНКУ БІОМАТЕРІАЛІВ ЄС

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The article is devoted to studying the role of logistics innovations as a key factor in enhancing enterprise competitiveness in the EU biomaterials market under conditions of circular economy transition and tightening regulatory requirements. The paper systematizes the main areas of logistics innovations relevant to biomaterials supply chains, including digital transparency, biohubs, advanced planning and forecasting tools, low-carbon and multimodal logistics, and circular logistics with reverse flows. The economic effects of implementing these innovations are substantiated through their impact on total logistics costs, working capital efficiency, supply reliability, and compliance-related risks. A comprehensive system of key performance indicators is proposed to quantitatively assess the influence of logistics innovations on the economic performance and resilience of biomaterials supply chains in the European Union.

Keywords: logistics innovations, biomaterials market, supply chains, enterprise competitiveness, circular logistics.

Стаття присвячена дослідженню ролі логістичних інновацій як одного з чинників підвищення конкурентоспроможності підприємств на ринку біоматеріалів у Європейському Союзі в умовах переходу до циркулярної економіки та посилення регуляторних вимог. Логістичні рішення відіграють важливу роль не лише у підвищенні операційної ефективності підприємств, а й у формуванні довгострокових конкурентних переваг на ринку біоматеріалів ЄС. У дослідженні систематизовано основні напрями логістичних інновацій, релевантних для біоматеріальних ланцюгів постачання, зокрема цифрову простежуваність, біохаби, інновації у сфері планування та прогнозування, мультимодальні перевезення й низьковуглецеву логістику, а також циркулярні логістичні моделі зі зворотними потоками. Обґрунтовано економічні ефекти впровадження логістичних інновацій через зниження сукупних логістичних витрат, скорочення потреби в оборотному капіталі, підвищення надійності та стабільності постачання, а також зменшення транзакційних ризиків. Встановлено, що економічні результати впровадження логістичних інновацій на підприємствах біоматеріального сектору значною мірою визначаються узгодженістю дій між учасниками ланцюгів створення вартості та інституційним середовищем їх функціонування в ЄС. Запропоновано систему ключових показників ефективності, яка поєднує фінансові, операційні, ризикові та екологічні метрики і дозволяє кількісно оцінювати вплив логістичних інновацій на економічні результати та стійкість ланцюгів постачання біоматеріалів у Європейському Союзі. Наукова новизна дослідження полягає у формуванні комплексного підходу до аналізу логістичних інновацій саме з позицій економічної конкурентоспроможності біоматеріалів, а не лише операційної ефективності або екологічних переваг. Отримані результати можуть бути використані підприємствами біоекономічного сектору для обґрунтування інвестиційних рішень, а також органами економічної політики й галузевими інституціями при розробленні програм підтримки розвитку біоматеріальних ланцюгів постачання в ЄС.

Ключові слова: логістичні інновації, ринок біоматеріалів, ланцюги постачання, конкурентоспроможність підприємств, циркулярна логістика.

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Statement of the problem. The European Union's biomaterials market is shaped by two mutually reinforcing processes: the structural decarbonization of the economy and the transition to circular models of production and consumption. Biomaterials (bio-based polymers and composites, fibers, biochemicals, biomass-based materials, materials from renewable raw materials and secondary biostreams) are becoming a strategic resource for EU industry, as they reduce dependence on fossil raw materials, lower the carbon footprint of products, and support the formation of new high-tech value chains [4].

In the industrial scaling phase, biomaterials compete not only on price or consumer properties, but also on their ability to ensure reliable supply, predictable batch quality, short order fulfillment times, transparent raw material provenance, and verifiable sustainability performance. These parameters directly depend on logistics and supply chain management [5].

Unlike many "traditional" material flows, biomaterial chains have a number of specific limitations: seasonality and spatial dispersion of bio-raw materials; high variability in quality and composition; sensitivity of some flows to storage conditions (humidity, temperature, transportation time); the need for pre-processing (drying, grinding, fractionation, stabilization); increased requirements for traceability and documentation of the value chain. In the absence of innovation, this leads to increased transaction and operating costs, increased insurance reserves, idle processing capacity, and, as a result, a loss of competitiveness [5; 7].

The problem is exacerbated by EU regulatory changes that emphasize eco-design, circularity, due diligence in supply chains, and transparent

reporting. For producers and consumers of biomaterials, this means a transition to a regime where "data becomes part of the product": market access and commercial attractiveness are increasingly determined by the ability to verify origin and impacts throughout the life cycle.

Analysis of recent research and publications. A review of current research shows that the competitiveness of the EU bioeconomy is seen as a function of innovation, resource security, and institutional capacity to scale up bio-based solutions. The European Commission's strategic documents emphasize the need to develop a competitive and sustainable bioeconomy, develop infrastructure, and remove barriers to investment in bioproduction and bio-based materials. At the same time, it highlights the existence of investment gaps in value chains, which hinders industrial scaling [5-7].

H. Stellingwerf, X. Guo, B. Behdani, and E. Annelink emphasize that bio-raw materials are characterized by high source dispersion, batch heterogeneity, and dependence on natural and climatic factors [6]. This increases the importance of "first mile" logistics (collection, consolidation, pre-processing), as well as quality management systems and contractual mechanisms capable of reducing uncertainty.

A separate area of research is related to the circular economy and reverse supply chains. The concepts of reverse logistics and reverse supply chains, developed by scientists M. Valipour, F. Mafakheri, and B. Gagnon, reveal the economic conditions under which the return of materials (reuse, repair, restoration, recycling) creates added value and at the same time requires new logistics networks, KPIs, and coordination between participants [7].

M. Pieroni, T. McAloone, and D. Pigosso analyze the digitization of supply chains (IoT, data platforms, digital twins, big data analytics, AI/ML) as a tool for increasing transparency, manageability, and sustainability [5]. Digital solutions are particularly important for biomaterials because they provide: (1) traceability of the origin of raw materials; (2) control of transportation and storage conditions; (3) automation of document flow and compliance confirmation; (4) reduction of costs for auditing, claims handling, and regulatory procedures.

Thus, a consensus is emerging in the current literature: logistics for biomaterials is not only a functional delivery process, but a critical competitive competence that affects cost, speed of scaling, customer trust, and the ability to

meet increased sustainability and transparency requirements.

Highlighting previously unresolved parts of the overall problem. Despite a significant body of scientific and applied research in the field of bioeconomics, logistics, and the circular economy, a number of unresolved issues remain in the current literature, limiting the formation of a comprehensive vision of the economic competitiveness of the biomaterials market in the European Union. Most studies focus on the technological characteristics of biomaterials or the macroeconomic aspects of the development of the bioeconomy, while the role of logistics is often considered in a fragmented manner, without a comprehensive analysis of its economic impact.

The impact of logistics innovations on the total cost of biomaterials remains insufficiently systematized, especially given the seasonality of supply, the heterogeneity of bio-raw materials, and the additional costs of their pre-processing. Scientific publications also lack integrated approaches to assessing the effectiveness of logistics solutions that would simultaneously take into account financial and operational indicators, as well as regulatory and risk factors. A separate scientific task is to analyze the impact of new European Union regulatory requirements in the field of eco-design and corporate sustainability reporting on the organization and cost of logistics processes in biomaterial supply chains.

In addition, the economic potential of reverse logistics chains in the context of ensuring resource security and stability of biomaterial supply remains insufficiently quantified. In general, there is a lack of applied analytical frameworks and key performance indicator systems adapted to the specifics of the EU biomaterials market in the literature, which necessitates further research and determines the scientific novelty and practical significance of this work.

Formation of the objectives of the article (task statement). The purpose of the article is to justify the role of logistics innovations as a key factor in increasing enterprise competitiveness in the EU biomaterials market under the transition to a circular and climate-neutral economy.

To achieve this purpose, the article sets out to solve the following scientific and practical objectives:

- to analyze the characteristics of the formation and functioning of biomaterial supply chains in the EU from the perspective of enterprise competitiveness;

- to identify the main directions of logistics innovations in biomaterial supply chains and their economic effects on enterprise performance;

- to assess the impact of logistics innovations on logistics costs, working capital turnover, and service level of enterprises;

- to examine the influence of EU regulatory requirements in the fields of eco-design, corporate reporting, and due diligence on the competitiveness of enterprises through logistics processes;

- to propose an analytical framework of key performance indicators for assessing the impact of logistics innovations on enterprise competitiveness in biomaterial supply chains.

Summary of the main research material.

The economic competitiveness of biomaterials lies in the ability of manufacturers to ensure an economically justified level of total cost, stable quality characteristics, and a reliable level of supply of biomaterials compared to traditional materials [2]. The supply chain plays a decisive role in this, within which logistics influences competitive positions through several key mechanisms: reducing overall logistics costs, minimizing losses and risks associated with supply uncertainty, accelerating capital turnover by reducing inventories and delivery times, increasing consumer confidence through traceability of the origin and movement of materials, and developing reverse logistics flows within circular production models [1].

Total logistics costs in biomaterial chains often include additional components: preliminary technological processing of bio-raw materials, humidity and temperature control, laboratory testing of batches, certification and origin verification costs, and digital data infrastructure costs. Uncertainty about the volume and quality of bio-raw materials increases the need for safety stocks and creates risks of processing capacity downtime. Accordingly, innovations that reduce variability and increase predictability have a direct economic effect by reducing inventory costs, increasing equipment utilization rates, and reducing unproductive losses [5].

Compliance and proof of sustainability are important competitive factors. With stricter corporate reporting and due diligence requirements, companies that can quickly provide verified data on suppliers and the origin of resources have lower transaction costs and a better position in negotiations with large buyers. This creates an opportunity to gain access to demanding supply chains and (in certain segments) sell products with higher margins [4; 5].

Based on a summary of current logistics practices, it is appropriate to identify five main areas of logistics innovation that are most relevant to the biomaterials market in the European Union. The first area is related to increasing the digital transparency and traceability of supply chains. This involves the introduction of digital data exchange platforms, the integration of suppliers into unified information systems, the use of IoT solutions to monitor the status of bio-raw material batches, and the digital support of documents and compliance confirmations, which ensures control and trust at all stages of material movement [6].

The second area covers infrastructure solutions for bio-raw materials, in particular the creation of regional bio-hubs, within which bio-raw materials are collected, consolidated, dried, crushed, and standardized. This is complemented by the use of modular storage systems, which reduce quality losses and increase supply stability. The third area concerns innovations in planning and forecasting, which include integrated S&OP processes, the use of digital twins of logistics networks, inventory and route optimization models, and artificial intelligence tools for forecasting seasonality, demand fluctuations, and logistics risks [6].

A separate group consists of solutions in the field of low-carbon and multimodal logistics, which involve optimizing routes and transport load levels, switching to more energy-efficient modes of transport, and developing cooperation in joint transport operations. The final area is circular logistics and the development of reverse supply chains, which cover systems for collecting, sorting, and returning biomaterials or waste to production, as well as the integration of logistics with reuse and recycling models [5-7].

Each of these areas has a specific economic impact profile. Infrastructure solutions help reduce specific transport costs and losses in the quality of bio-raw materials, digital tools reduce the costs of regulatory compliance and associated risks, innovations in planning reduce the need for inventories and increase the resilience of supply chains to external shocks, multimodal solutions reduce fuel costs and carbon footprint, while reverse logistics chains reduce dependence on primary bio-raw materials and create additional secondary revenue streams.

For a practical assessment of the feasibility of implementing such innovations, it is advisable to use a comprehensive performance framework that combines financial, operational, and risk and compliance metrics. A basic set of key

performance indicators for biomaterial supply chains is presented in Table 1.

The results of the generalization presented in the table show that the economic effect of logistics innovations in biomaterial supply chains is multidimensional and is formed through the interaction of cost, time, service, capital-intensive, and risk-compliance parameters. The proposed integrated approach to evaluating efficiency, which combines indicators of total logistics costs (TLC), lead time, service level (OTIF), working capital requirements, and compliance risk level, allows moving from local optimization of individual logistics functions to a systematic analysis of the competitiveness of biomaterial supply chains.

As shown in the table 1, digital solutions in the field of transparency and traceability reduce transaction costs and regulatory risks through data standardization, document flow automation, and faster information exchange between value chain participants. The measurable effects are reflected in reduced lead times, increased OTIF rates, and lower audit and compliance costs, which is particularly critical in the context of the EU's tightening regulatory requirements for sustainability and due diligence in supply chains.

Infrastructure innovations, in particular the creation of bio-raw material hub networks, have the most significant direct impact on reducing total logistics costs. The consolidation of bio-raw material flows, primary processing, and standardization at the hub level reduce specific transportation costs, quality losses, and specification variability. This, in turn, is reflected in a reduction in safety stocks, an increase in the utilization rate of processing equipment, and a reduction in downtime, which has a significant impact on the total cost of biomaterials [7].

Innovations in planning and forecasting, including integrated S&OP processes, digital twins of logistics networks, and artificial intelligence models, directly impact working capital management efficiency [5]. According to the summary indicators in the table, their implementation is accompanied by a reduction in inventory levels, a decrease in logistics cycle time, and an increase in overall equipment effectiveness (OEE), which is critical for capital-intensive bioprocessing enterprises.

Solutions in the field of multimodal and low-carbon logistics create a combined economic effect that combines a reduction in operating costs with the minimization of strategic risks associated with the decarbonization of the economy. Optimizing routes and transport loads,

Table 1

KPI for evaluating the effects of logistics innovations in biomaterial chains

Area of logistics innovation	Key economic effects	Key KPIs for assessing the effect
Digital transparency and traceability of supply chains	Reduced transaction costs and compliance risks; increased consumer and buyer confidence; reduced administrative procedures time	Percentage of traceable shipments; compliance lead time; compliance costs as a percentage of turnover; number of non-compliances/audit findings
Infrastructure solutions for bio-raw materials (biohubs)	Reduction of specific transport costs; reduction of quality losses; improvement of supply stability and capacity utilization	Logistics costs per unit of bio-based raw materials; level of losses/spoilage, %; capacity utilization rate; variability of supply volumes
Innovations in planning and forecasting	Reduced inventory requirements; accelerated capital turnover; reduced downtime and shortage risks	Inventory turnover; safety stock level; demand forecast accuracy; share of processing capacity downtime
Low-carbon and multimodal logistics	Reduction in fuel and transportation costs; reduction in carbon footprint; increased compliance with EU climate requirements	Share of multimodal transport, %; transport load factor; transport costs per tonne
Circular logistics and reverse supply chains	Reduced dependence on primary bio-raw materials; creation of secondary revenue streams; increased resource efficiency	Share of secondary raw materials in production, %; material return rate; savings on primary resource purchases; income from by-products/secondary flows

Source: compiled by the author based on [1; 5; 6; 7]

switching to energy-efficient modes of transport, and cooperating in joint transport operations reduce fuel costs and carbon emissions per unit of output, which improves customer compliance and reduces the risk of losing access to green market segments [7].

Circular logistics and the development of reverse supply chains, as shown in the table, have a predominantly long-term strategic effect. They contribute to reducing dependence on primary bio-raw materials, stabilizing the cost base, and generating additional streams of recovered value, which increases the sustainability of biomaterial manufacturers' business models in conditions of price and resource volatility.

Therefore, the maximum economic effect is achieved not through the implementation of individual logistics innovations, but through their combination within a coordinated supply chain architecture. Logistics innovations are network-based, and their effectiveness increases significantly when there is coordination between value chain participants, harmonization of data standards, and development of a common infrastructure. It is in this configuration that logistics becomes a key factor in scaling biomaterials from innovative niches to mass markets in the European Union.

Conclusions. The study substantiates that logistics innovations are one of the key factors in increasing the economic competitiveness of the biomaterials market in the European Union in the context of the transition to a circular and climate-neutral economy. It has been shown that at the stage of industrial scaling, biomaterials compete not only in terms of technological characteristics or price, but also in terms of their ability to ensure stable supply, predictable quality, reduced order fulfillment times, and proven sustainability, which is directly determined by the efficiency of logistics and supply chain management.

It has been established that the specifics of biomaterial flows – seasonality, spatial dispersion of raw materials, variability in quality, sensitivity to transportation and storage conditions, and increased traceability requirements – generate additional logistics costs and risks, which, in the absence of innovation, reduce the economic attractiveness of biomaterials compared to traditional materials. In this context, logistics is not a supporting function, but a strategic competitive competence.

Based on a summary of current practices and scientific approaches, five key areas of logistics innovation relevant to the EU biomaterials

market have been systematized: digital transparency and traceability of supply chains; infrastructure solutions for bio-based raw materials; innovations in planning and forecasting; low-carbon and multimodal logistics; circular logistics and reverse supply chains. It has been proven that each of these areas forms a specific economic effect profile, affecting total cost, capital turnover, service level, and compliance risks.

A framework of key performance indicators has been proposed to assess the effectiveness of implementing logistics innovations in biomaterial supply chains, combining financial, operational, and risk-compliance metrics. Its application allows moving from a fragmented assessment of individual logistics solutions to a comprehensive analysis of their economic

impact, taking into account EU regulatory requirements and the specifics of bio-raw material flows.

The results show that the greatest potential for increasing competitiveness lies in integrated logistics solutions that simultaneously reduce costs and increase the transparency and manageability of supply chains. Coordination of value chain participants, harmonization of data standards, and development of shared infrastructure are critical conditions for scaling biomaterials from innovative niches to mass markets in the European Union. Prospects for further research include a quantitative assessment of the risk-adjusted effects of logistics innovations and the adaptation of the proposed analytical framework to specific segments of the biomaterials market.

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