

The Role of Green Logistics as a Determinant of Supply Chain Efficiency and National Export Competitiveness

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Abstract

Green logistics has emerged as a strategic tool for enhancing supply chain efficiency and improving national export competitiveness in the global sustainability era. This study examines the dual impact of environmentally oriented logistics practices on operational performance and trade outcomes. By implementing practices such as renewable energy utilization, reverse logistics, AI-based route optimization, electric transportation, and sustainable packaging, organizations can reduce operational costs, minimize carbon emissions, and optimize resource allocation. At the macroeconomic level, green logistics enhances the reliability of exports, compliance with international sustainability standards, and access to premium markets governed by environmental regulations. The study demonstrates that green logistics is not only an environmental initiative but also a strategic mechanism that integrates operational efficiency with competitive advantages in global trade. The findings provide critical insights for policymakers, logistics managers, and exporters seeking to strengthen national supply chains and global trade performance.

Keywords: Green Logistics; Supply Chain Efficiency; Export Competitiveness; Sustainable Supply Chain; Environmental Compliance

Introduction

Global trade has entered a transformative phase in which environmental sustainability no longer functions merely as a regulatory expectation but has become a critical determinant of long-term economic advantage. Countries and industries across the world are increasingly required to implement low-carbon logistics systems, climate-responsive supply chains, and comprehensive traceability mechanisms as prerequisites for maintaining access to high-value markets. This shift reflects the broader restructuring of global commerce, where sustainability commitments, carbon neutrality goals, and green trade regulations now shape patterns of production, transportation, and international market integration. As a result, green logistics has evolved from an ecological initiative into a strategic foundation for strengthening national supply chain stability, export performance, and overall global competitiveness.

This transition is particularly evident in emerging economies, where logistics efficiency, environmental compliance, and digital capability have become decisive factors for export growth and participation in global value chains. Recent studies show that countries with well-developed, environmentally oriented logistics systems gain stronger competitive advantage due to lower emissions, greater shipping reliability, and improved alignment with sustainability-regulated trade frameworks (Fan et al., 2022; Huong et al., 2024; Le et al., 2022). Logistics

capacity is now recognized as a core enabler of national competitiveness, influencing not only transport performance but also the strategic positioning of entire export sectors (Filassi & de Oliveira, 2021; Bugarčić et al., 2023). Moreover, the Green Logistics Performance Index (GLPI) has emerged as a key predictor of export capability, demonstrating that improvements in green logistics are directly linked to increased trade flows and reduced vulnerability to non-tariff environmental barriers (Xuan et al., 2023; Jasim, 2024).

In addition to regulatory pressures, the global commitment to carbon neutrality is accelerating the adoption of sustainable logistics practices. Many economies now embed environmental requirements such as carbon border adjustments, product-level life-cycle assessments, and mandatory sustainability reporting into their trade policies. As firms seek to align with these evolving requirements, green logistics capabilities such as low-emission transportation, energy-efficient warehousing, and environmentally responsible routing have become essential drivers of cost efficiency and trade readiness. Empirical findings across Asia confirm that green innovation and environmental logistics practices significantly enhance supply chain performance and support carbon-neutral economic transitions (Liu et al., 2023; Tetteh et al., 2025). This aligns with the rapid evolution of logistics services in countries pursuing modernization agendas, where digitalization, AI applications, and green technologies strengthen both operational resilience and export competitiveness (Chang et al., 2022; Van Vo & Nguyen, 2023).

From an operational standpoint, green logistics contributes to supply chain efficiency through a combination of technological, energy, and process innovations. The adoption of renewable energy, the integration of reverse logistics, and the implementation of AI-based route optimization enhance delivery precision, reduce waste, and improve resource allocation (Jamayat et al., 2025; Hussain et al., 2025; Jahagirdar, 2025). These improvements are further supported by evidence showing that environmentally oriented logistics investments within large-scale trade corridors such as those associated with China's Belt and Road Initiative generate both economic and environmental benefits by strengthening the long-term sustainability of cross-border logistics infrastructure (An et al., 2021). Accordingly, green logistics knowledge, workforce capability, and organizational intellectual capital play increasingly important roles in determining the success of green transitions within national and regional supply chains (Van Vo & Nguyen, 2023).

Taken together, existing evidence highlights a global shift in which green logistics is no longer viewed as an optional or supportive component of the supply chain, but rather as a primary driver of national competitiveness, economic resilience, and sustainable export performance. As nations intensify efforts to comply with global sustainability standards and align with carbon-neutral trade ecosystems, green logistics emerges as a core strategic element that integrates environmental responsibility with economic advantage. Within this evolving landscape, understanding the dual impact of green logistics on supply chain efficiency and export competitiveness becomes essential for policymakers, logistics managers, and industries seeking to sustain long-term relevance in the sustainability-driven global trading system.

Methods

This study employs a systematic literature review (SLR) approach to identify, evaluate, and synthesize scientific findings related to green logistics, supply chain efficiency, and export competitiveness within the context of global sustainability demands. The SLR method was chosen to ensure that the analysis is comprehensive, transparent, and replicable, enabling the consolidation of existing knowledge while identifying consistent patterns and research gaps across multiple academic domains. The review process followed four structured stages: (1) identification of issues, which involved defining the scope and key research questions surrounding the relationship between green logistics and export performance; (2) screening of scientific publications to eliminate duplicate, non-peer-reviewed, or methodologically weak sources; (3) extraction of relevant findings from selected studies based on core variables such as environmental logistics practices, supply chain indicators, and export performance metrics; and (4) synthesis for conclusion development, in which empirical insights were categorized into thematic clusters to construct an integrated understanding of the topic.

To ensure data accuracy and relevance, searches were conducted across leading scientific databases Scopus, DOAJ, ScienceDirect, Google Scholar, and Emerald with a focus on peer-reviewed articles published between 2020 and 2025. This timeframe was selected to capture the most recent developments in green logistics innovation and the increasing integration of sustainability standards into international trade. Keyword combinations such as “green logistics,” “supply chain sustainability,” “low-carbon logistics,” “export performance,” and “global trade competitiveness” were applied using Boolean operators to refine the search process. Only empirical studies written in English and indexed in reputable journals were included to guarantee the credibility of the synthesized evidence. Through this methodological design, the SLR provides a robust foundation for understanding how green logistics shapes supply chain efficiency and export competitiveness, while also uncovering strategic insights relevant to policymakers, industrial practitioners, and academic researchers.

To provide a clearer overview of the methodological structure employed in this study, the stages of the research process are summarized in the following flowchart. This visual representation outlines the sequential steps taken to ensure that the systematic literature review was conducted rigorously, transparently, and in alignment with academic standards.

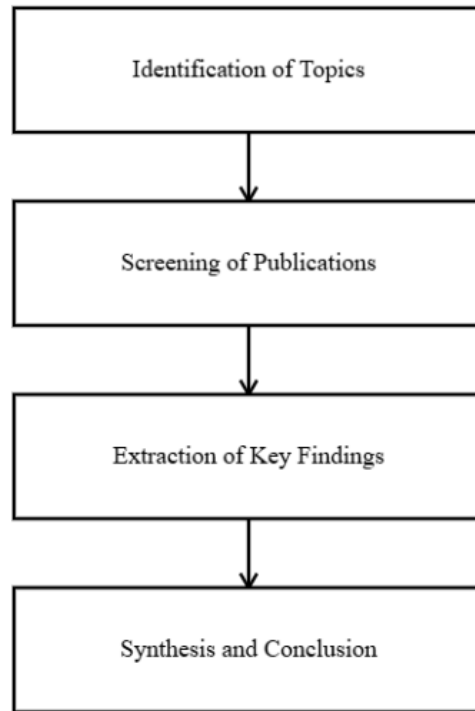


Figure 1. Systematic Literature Review Process

The research flowchart illustrates the four main stages undertaken in the systematic literature review. The first stage, identification, involves determining the scope, keywords, and core themes of the research topic to ensure relevance to green logistics, supply chain efficiency, and export competitiveness. The second stage, screening, focuses on selecting scientific articles that meet eligibility criteria, including publication year, peer-review status, and thematic suitability. The third stage, extraction, consists of gathering critical information and empirical findings from the selected studies, allowing the research to map how green logistics practices influence both internal and external performance indicators. The final stage, synthesis, integrates the extracted data and interprets the research outcomes to produce conclusions that are analytically aligned with the study's objectives. Overall, the flowchart reflects a structured and systematic approach that ensures the validity, reliability, and depth of the research results.

Results

The majority of studies indicate that green logistics substantially improves supply chain efficiency by promoting energy optimization, waste reduction, logistics digitalization, and resource allocation accuracy. These practices contribute to operational cost reduction, improved delivery precision, and shorter lead time (Jamayat et al., 2025; Hussain et al., 2025; Waiyawuththanapoom et al., 2025). In parallel, green logistics also exerts a strong impact on national export competitiveness. Countries with high GLPI show higher export volumes, particularly due to logistics reliability and decreasing emissions (Fan et al., 2022; Huong et al., 2024; Popovskiy et al., 2025). Green logistics also strengthens international market access by meeting sustainability-based trade requirements and environmental standards.

To provide a more detailed understanding of how green logistics contributes to the operational performance of supply chains, the specific practices and their efficiency outcomes

are organized in Table 1. This table summarizes the core sustainability-driven logistics initiatives identified in previous studies and explains their direct impacts on supply chain efficiency.

Table 1. Green Logistics Practices and Impacts on Supply Chain Efficiency

Green Logistics Practice	Efficiency Outcome	Sources
Renewable energy use	Reduced operational energy cost	Jamayath et al., 2025; Hussain et al., 2025
Reverse logistics	Lower waste & improved warehouse accuracy	Hussain et al., 2025
AI route optimization & EV transportation	Shorter lead time & reduced fuel/emissions	Trivellas et al., 2020; Jahagirdar, 2025
Sustainable packaging	Lower material usage and improved durability	Pham et al., 2023

Table 1 provides a comprehensive overview of the primary green logistics practices and their direct impacts on supply chain efficiency. The table demonstrates that each sustainability-oriented initiative contributes to operational improvements through a different performance mechanism. For example, the adoption of renewable energy reduces dependence on fossil fuels and lowers facility-level operating costs, indicating that environmental investments generate financial returns rather than additional expenses. Reverse logistics, on the other hand, enhances warehouse productivity and material utilization by extending product and packaging life cycles, thereby minimizing waste accumulation and unnecessary procurement.

Technological innovations emerge as another dominant efficiency driver. AI-powered route optimization and the use of electric vehicle transport reduce fuel consumption and shorten lead times, enabling logistics companies to synchronize delivery schedules more accurately and reduce uncertainty in transit. Similarly, sustainable packaging improves durability and cubic efficiency, which minimizes material waste and increases the volume of goods that can be transported in a single shipment. Taken together, the mechanisms presented in Table 1 reveal a clear pattern: green logistics is not limited to carbon reduction initiatives, but rather a multidimensional strategy that improves speed, precision, cost-efficiency, and system responsiveness. This implies that environmental sustainability and economic performance are not trade-offs; instead, they reinforce one another within well-managed logistics systems.

While Table 1 explains the contribution of green logistics to internal supply chain efficiency, it is also important to illustrate how sustainability-driven logistics simultaneously influences both operational and economic outcomes. Therefore, the following diagram visualizes the dual impact of green logistics by positioning supply chain efficiency and export competitiveness as interconnected outputs of environmentally oriented logistics performance.

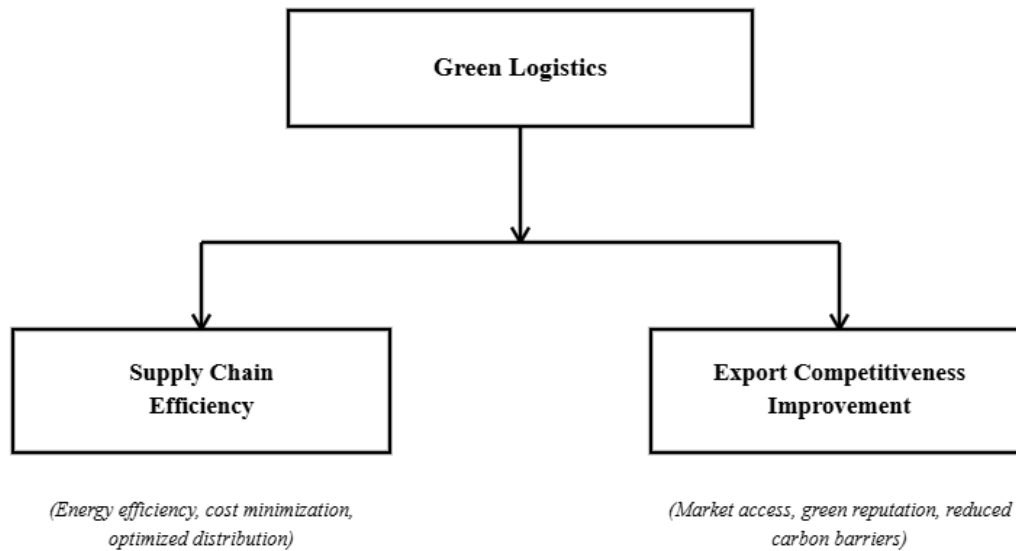


Figure 2. Diagram Dual Impact of Green Logistics

The diagram illustrates the dual-impact model of green logistics, emphasizing its role as a strategic driver of both supply chain performance and export competitiveness. At its core, green logistics fosters internal optimization by reinforcing operational excellence. Waste reduction, energy efficiency, route optimization, and sustainable transportation lead to faster distribution cycles, more efficient use of resources, and reduced vulnerabilities in logistics operations. These improvements help organizations recover from disruptions more quickly, stabilize inventory flow, and keep logistics costs under control features that are essential in today’s increasingly volatile global supply networks.

Externally, these operational improvements drive measurable economic advantages in international trade. When logistics reliability increases and carbon emissions decrease, exporting countries improve their compliance with global sustainability standards, opening access to markets that are increasingly regulated by environmental requirements. Furthermore, low-emission logistics strengthens the reputation of producers and exporters, positioning them as responsible and future-oriented suppliers in the global marketplace. This increases buyer trust, accelerates trade partnerships, and helps exporters overcome green trade barriers that might otherwise restrict market entry.

Importantly, the diagram also implies a reinforcing cycle: internal efficiency enhances export competitiveness, and exposure to international sustainability competition stimulates further logistics innovation and environmental commitment. Therefore, green logistics is not simply a functional improvement to supply chains, but a long-term strategic instrument for national competitiveness and economic resilience. The visual emphasizes that countries and industries that successfully adopt green logistics are more likely to maintain export growth and withstand global trade pressures in the sustainability era.

Discussion

The findings reinforce that green logistics is reshaping economic competition by simultaneously driving supply chain efficiency and export performance. Internally, sustainable logistics strengthens operational excellence by improving energy efficiency, reducing warehouse waste, and enabling predictive and real-time transportation planning (Jamayat et al., 2025; Hussain et al., 2025; Pham et al., 2023). These internal improvements demonstrate that green logistics practices are not merely operational adjustments but structural transformations that enhance the reliability, agility, and resilience of supply chain systems. They generate a cumulative effect in which cleaner technologies and efficiency-oriented logistics routines interact to reduce process variability, prevent disruptions, and increase throughput. This is consistent with research showing that logistics capability and internal process integration generate sustainable competitive advantage, especially in industries where supply chain responsiveness directly influences export performance (Filassi & de Oliveira, 2021; Chang et al., 2022).

Furthermore, the incorporation of digital technologies such as AI-driven routing, smart sensors, and energy monitoring systems creates logistics ecosystems that support real-time decision-making and environmental transparency. These innovations enable firms to synchronize inventory movement, avoid congestion, optimize vehicle loading, and reduce fuel consumption, ultimately contributing to both environmental sustainability and cost competitiveness. Such outcomes are aligned with empirical evidence showing that digital green complementarities significantly enhance supply chain performance and accelerate progress toward carbon neutrality across Asia (Liu et al., 2023; Tetteh et al., 2025). Green logistics knowledge and organizational intellectual capital further strengthen this process by facilitating the adoption of advanced technologies and enabling firms to operationalize sustainability-based workflow improvements (Van Vo & Nguyen, 2023).

In addition to internal efficiencies, green logistics contributes substantially to broader economic outcomes by enhancing national and firm-level export competitiveness. Export markets today increasingly favor suppliers that demonstrate compliance with environmental standards, carbon reporting obligations, and sustainability certifications. As such, green logistics functions as a mechanism through which firms improve logistics reliability, strengthen documentation accuracy, and reduce shipment-related emissions factors that are essential for penetrating environmental-regulated markets (Fan et al., 2022; Huong et al., 2024). Evidence from emerging economies further shows that GLPI improvements strongly correlate with export volume growth, enabling countries to compete more effectively in global value chains while reducing their vulnerability to non-tariff environmental barriers (Le et al., 2022; Jasim, 2024).

The external dimension of green logistics also intersects with reputational capital and market perception. Firms and nations that embrace sustainability-oriented logistics practices enhance their brand legitimacy, signaling responsibility, reliability, and forward-looking capability to international buyers. This reputational advantage is increasingly important in global markets where supply chain transparency and emission reduction commitments influence buyer decisions and long-term partnerships. Prior studies confirm that environmentally oriented logistics operations such as low emission transportation, circular packaging, and climate-resilient distribution systems contribute directly to positive trade

outcomes and strengthen strategic linkages with global partners (An et al., 2021; Bugarčić et al., 2023).

Moreover, as global trade regulations adopt stricter environmental guidelines such as the Carbon Border Adjustment Mechanism (CBAM) and life-cycle assessment requirements the ability of exporters to meet these standards becomes a determinant of market access. Green logistics thus enables firms not only to comply with external requirements but also to reduce the risk of trade penalties, improve export continuity, and gain preferential access to high-value, sustainability-sensitive markets (Popovskiy et al., 2025; Qazi, 2025; Li et al., 2022). This provides further support for the argument that environmental management and export performance are increasingly interdependent outcomes of the same strategic capability set.

Importantly, the dual impact of green logistics is self-reinforcing. Internal efficiency gains strengthen external competitiveness by improving reliability, reducing delays, and enabling firms to demonstrate environmental performance metrics demanded by global buyers. Conversely, exposure to international environmental expectations incentivizes firms to invest more deeply in internal sustainability innovations, digitalization, and logistics capability development. This cyclical relationship is reflected in the success of SMEs and larger exporters that adopt green export strategies, where innovation readiness and sustainability-based activities mediate export growth (Singh et al., 2024). Collectively, these insights show that green logistics is no longer a reactive response to external pressures but a proactive and strategic approach that integrates operational excellence with long-term export advantage.

Taken together, the evidence indicates that sustainability-driven logistics represents a structural shift in global competition. Firms and countries that invest in green logistics enhance their supply chain resilience, reduce environmental risks, strengthen their participation in global markets, and increase their ability to adapt to future carbon-oriented trade regimes. Conversely, economies that fail to develop green logistics capabilities face higher trade vulnerability, increased operational costs, and reduced competitiveness in markets governed by sustainability norms (Ellison et al., 2024; Barut et al., 2023). The findings therefore underscore that green logistics is not merely an environmental compliance activity but a strategic necessity shaping the future architecture of global supply chains and export dynamics.

Conclusion

Green logistics has emerged as a critical strategic approach for enhancing both operational efficiency and export competitiveness in the context of global sustainability. The findings of this study confirm that the integration of environmentally friendly logistics practices including renewable energy utilization, reverse logistics, electric transport, AI-based route optimization, and sustainable packaging directly contributes to more resilient, cost-efficient, and responsive supply chains. These practices not only lower operational costs and improve warehouse management but also facilitate predictive and real-time planning that enhances the overall performance of logistics networks.

At the macroeconomic level, green logistics significantly strengthens international trade performance by ensuring compliance with global sustainability standards and environmental regulations. Exporters adopting green logistics achieve higher reliability, reduced carbon emissions, and a stronger reputation in global markets, allowing them to access premium

markets, overcome green trade barriers, and align with net-zero and carbon-neutral policies of importing countries. This dual impact demonstrates that green logistics is not merely an environmental compliance measure but a comprehensive strategic tool that integrates operational efficiency with competitive advantage in global trade.

Moreover, the adoption of green logistics has broader implications for national industrial policy and sustainable economic growth. It encourages innovation, promotes technological adoption in logistics and transportation, and enhances the capacity of industries to meet both domestic and international sustainability standards. Consequently, countries and firms that successfully implement green logistics are better positioned to achieve long-term supply chain resilience, maintain export growth, and sustain competitiveness in increasingly regulated and environmentally conscious global markets.

In conclusion, green logistics functions as a dual-impact mechanism that optimizes internal supply chain performance while simultaneously enhancing external export competitiveness. Its strategic implementation is essential for nations and industries seeking to thrive in a global economy increasingly shaped by sustainability pressures, environmental regulations, and carbon-conscious trade requirements. Future research should explore longitudinal impacts, sector-specific dynamics, and policy interventions that maximize the synergistic benefits of green logistics on both operational and trade performance.

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