From Emissions to Efficiency: A Narrative Review on Sustainable Transportation and Logistics

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ABSTRACT: This narrative review explores innovation in green logistics, covering technologies, logistics models, regulations, consumer behavior, and global implementation. It highlights the environmental urgency driving sustainable logistics and identifies key research gaps. Using a systematic method, peer-reviewed articles were analyzed to reveal that technologies like electric vehicles, hydrogen fuel, biodiesel, AI, IoT, and blockchain improve both environmental and operational outcomes. Sustainable models such as multimodal transport, circular logistics, and collaborative distribution reduce emissions and enhance efficiency. The review emphasizes the role of supportive policies, financial incentives, and stakeholder collaboration, with case studies from Germany, China, India, and Malaysia illustrating successful integrated approaches. However, barriers like limited funding, poor infrastructure, and institutional resistance persist. The study calls for cohesive policies, stronger private sector roles, and interdisciplinary research to support the global shift toward sustainable logistics.

Keywords: Green Logistics, Sustainable Transportation, Green Supply Chain, Eco-Innovation, Smart Logistics, Policy And Infrastructure, Digital Technologies.

INTRODUCTION

In recent years, the imperative to transition toward green logistics systems has garnered substantial global attention, driven by increasing concerns over climate change, environmental degradation, and public health. The conventional logistics sector, long reliant on fossil fuel-based transportation and inefficient distribution systems, contributes significantly to global greenhouse gas emissions. According to Jarašūnienė and Bazaras (2023), the transportation sector is responsible for approximately 24% of total global carbon emissions, with logistics playing a prominent role in this figure. In response, global and regional efforts have emerged to reorient traditional logistics structures toward more sustainable alternatives. For instance, European nations have tightened emission regulations and prioritized low-emission transport infrastructure, while various countries

have begun allocating substantial public and private investments toward green transportation solutions (Usvakangas et al., 2024; Yu et al., 2024).

This shift toward sustainable logistics is not only driven by environmental necessity but also by evolving consumer preferences and competitive market dynamics. A growing segment of environmentally conscious consumers demands cleaner, faster, and more efficient delivery services. In turn, companies have started integrating green logistics practices into their supply chain operations to meet these expectations and maintain market relevance (Orji et al., 2019). The integration of sustainable practices is increasingly seen as a strategic necessity, supported by policies and incentives that encourage greener modes of transportation and logistics innovation (Du et al., 2023). Despite this momentum, the pathway to achieving large-scale adoption of green logistics remains complex and fraught with challenges.

The environmental burden of traditional logistics systems underscores the urgency of this transition. Emissions from fossil-fuel-powered logistics vehicles contribute not only to climate change but also to urban air pollution, adversely affecting public health (Orji et al., 2019). Additionally, outdated logistics practices often neglect the efficiency gains attainable through technological advancements such as electric vehicles (EVs), route optimization algorithms, and energy-efficient infrastructure (Cheng et al., 2023; Grzesiak & Sulich, 2023). Without a proactive shift to green logistics, these inefficiencies will continue to exacerbate environmental and economic issues, making sustainable logistics no longer optional, but essential.

At the forefront of addressing this issue are technology-based innovations that offer viable solutions to the inefficiencies inherent in traditional logistics systems. The implementation of the Internet of Things (IoT), artificial intelligence, and machine learning in logistics operations can significantly enhance transportation efficiency and environmental performance (Liu & Ma, 2022). Moreover, the rise of e-commerce has shifted consumer expectations toward rapid delivery systems, necessitating reforms in logistics strategies that accommodate both speed and sustainability (Zahoor et al., 2024; Kong et al., 2024). These market trends have accelerated the need for innovation in green logistics, with organizations recognizing that maintaining status quo practices risks both environmental harm and market obsolescence.

Societal support for green logistics initiatives has concurrently grown, spurred by heightened environmental awareness. Contemporary consumers are increasingly aligning purchasing decisions with sustainability values, incentivizing companies to adopt environmentally friendly practices (Du et al., 2023; Jou et al., 2023). Failure to align with these shifting preferences can lead to reputational and financial risks, as evidenced by a growing body of literature highlighting market shifts toward sustainability-driven brands (Alagarsamy & Ramdas, 2024; Liu & Wu, 2024). Complementing consumer trends are policy interventions aimed at fostering greener logistics, including tax incentives, carbon pricing mechanisms, and infrastructure funding (Zhang et al., 2024).

Nevertheless, skepticism surrounds the authenticity of some corporate sustainability initiatives, with critics pointing to 'greenwashing' practices that misrepresent environmental performance. To address this issue, robust mechanisms for environmental auditing and sustainability impact

assessment are essential (Deng et al., 2022). Transparent reporting frameworks and third-party verifications can help ensure that green logistics claims reflect substantive progress rather than mere marketing strategies. As such, developing an in-depth understanding of green logistics concepts and their practical implementation is critical to shaping sustainable and accountable logistics systems.

Despite increasing interest, there remain notable gaps in the literature regarding the real-world implementation of green logistics technologies. Many studies have highlighted the potential of innovations such as EVs, smart logistics systems, and AI-driven optimization (Nicoletti & Appolloni, 2024; Orji et al., 2019). However, they often overlook critical socio-economic and political factors influencing adoption, such as regulatory environments, market infrastructure, and stakeholder engagement (Jarašūnienė & Bazaras, 2023). Emerging economies, in particular, face significant hurdles including inadequate infrastructure and weak public-private collaboration, limiting the practical deployment of sustainable logistics systems (Orji et al., 2019).

Furthermore, while substantial research exists on technological solutions, there is limited exploration of how these innovations can be effectively integrated into existing logistics systems. Much of the literature focuses on discrete technologies without a systems-level perspective that considers logistical networks as dynamic, multi-actor ecosystems (Alibakhshi et al., 2024). Additionally, stakeholder dynamics—especially the role of consumer behavior, government policy, and private-sector investment—are frequently underexplored, despite being crucial to the successful uptake of sustainable practices (Demir et al., 2022).

The primary aim of this review is to analyze the current state of innovation in green transportation and logistics by identifying key technological, behavioral, regulatory, and infrastructural factors influencing the transition to sustainability. Through a thematic synthesis of empirical and theoretical studies, this review seeks to delineate best practices, identify critical barriers, and highlight emerging trends that define the evolving landscape of sustainable logistics. By offering a comprehensive evaluation, this work aims to contribute to academic and policy discussions surrounding the pathways toward environmentally sound logistics systems.

This review focuses on green logistics practices across diverse geographic regions, including both developed economies with established sustainability frameworks and emerging economies confronting infrastructural and regulatory challenges. By encompassing a range of case studies and regional contexts, the review aims to provide nuanced insights into how local conditions shape the adoption and implementation of sustainable logistics practices. Particular attention is given to the dynamics in the BRICS nations and the European Union, where sustainability policies and industrial strategies exert significant influence on logistics reform.

In sum, the transformation of logistics systems from conventional to sustainable models represents a multidimensional challenge requiring coordinated action across technological, institutional, and societal domains. The growing body of literature on green logistics reflects the urgency of this transformation, yet also underscores persistent research gaps related to implementation, stakeholder dynamics, and systemic integration. This review endeavors to bridge these gaps by

offering a critical synthesis of contemporary research, thereby advancing scholarly understanding and supporting the development of more effective green logistics strategies.

METHOD

This study employed a systematic literature review approach to examine the landscape of green transportation initiatives. The methodology was designed to ensure comprehensive coverage of the most recent and relevant academic discourse in the field of green logistics and sustainable transportation. The overarching objective was to capture a wide spectrum of empirical findings, theoretical frameworks, technological innovations, and policy-oriented discussions that are instrumental in shaping the implementation and evolution of green transportation strategies globally.

To begin, the literature retrieval process was conducted using multiple electronic databases widely acknowledged for their academic rigor and breadth of indexed journals. These included Scopus, Web of Science, and Google Scholar. The selection of these databases was motivated by their extensive coverage of interdisciplinary research, including transportation science, environmental studies, supply chain management, and policy analysis. Searches were conducted during a four-week period, with iterative refinement of search queries to ensure completeness and relevance.

A critical component of the literature retrieval process was the construction of effective keyword combinations. The primary keywords used included "Green Logistics," "Sustainable Transportation," "Zero-Emission Transport," "Eco-Innovation in Logistics," and "Sustainable Supply Chain Management." These keywords were selected based on their recurrence in high-impact publications and their alignment with the thematic focus of the review. In order to enhance the precision and recall of the search, Boolean operators and advanced search techniques were employed. Keyword combinations such as "Green logistics AND innovation," "Sustainable supply chain AND zero-emission," and "Eco-innovation AND logistics sustainability" were tested and refined. Further, complex queries like "Green logistics AND (electric vehicles OR hybrid transportation)," and "(Sustainable transportation OR eco-friendly transport) AND (barriers OR challenges)" were used to retrieve studies that offered insights into both technological and socio-economic dimensions of green transportation.

The inclusion and exclusion criteria were carefully established to maintain the academic rigor and thematic relevance of the literature selected for review. One of the primary inclusion criteria was the publication year. Only articles published within the last ten years were considered, with the aim of capturing the most recent advancements and trends in green logistics and transportation. This criterion ensured that the review reflects contemporary challenges, technological breakthroughs, and policy developments.

Study type was another essential criterion in determining the relevance and quality of the included literature. Only peer-reviewed journal articles, conference proceedings, and reports from

authoritative institutions were selected. These documents typically offer empirical or theoretical depth, ensuring that the findings are grounded in systematic methodologies and replicable research designs. Articles excluded from the review included non-peer-reviewed sources, opinion editorials, anecdotal reports, and studies lacking empirical evidence or a theoretical framework. This exclusion was critical in filtering out unsubstantiated claims and ensuring the academic reliability of the review.

Geographic diversity was a core consideration during the selection process. Studies from a range of regions were included to provide a global perspective on green transportation initiatives. Emphasis was given to research conducted in regions actively engaged in sustainable logistics reforms, such as Europe, North America, and parts of Asia. These regions were selected due to their substantial regulatory developments, technological investments, and emerging innovations in transportation. Conversely, studies focusing on regions with limited or negligible relevance to sustainable logistics were excluded to preserve the contextual integrity of the review.

Demographic scope was also considered in framing the inclusion criteria. The review included studies that addressed various stakeholders, including consumers, transportation service providers, logistics companies, governmental institutions, and non-governmental organizations. This broad spectrum was essential for understanding the different motivations, challenges, and impacts experienced by each stakeholder group in relation to green transportation. Studies that failed to specify the demographic or organizational context were excluded, particularly if their findings could not be generalized or meaningfully connected to broader systems.

In addition, language was used as a filtering mechanism to ensure consistency and accessibility of the reviewed literature. Only articles published in English were included in the final review. This decision was based on the need for uniformity in analysis and comprehension, as well as practical constraints associated with translation. While this may have excluded potentially valuable insights from non-English literature, the trade-off was deemed necessary to maintain methodological rigor and feasibility.

Relevance to the core themes of the study served as the final filtering layer. Selected publications needed to directly address themes such as sustainability, green technologies, transportation innovation, and policy impact within logistics systems. Articles that primarily focused on unrelated sectors or diverged significantly from the green transportation agenda were excluded. This helped maintain a clear focus throughout the review and ensured that the synthesis of literature remained coherent and aligned with the study's objectives.

The process of literature selection was conducted in multiple stages to enhance accuracy and objectivity. Initially, titles and abstracts of retrieved articles were screened to determine their preliminary relevance. Articles that appeared relevant were then subjected to full-text review to assess their alignment with inclusion criteria. This was followed by a quality appraisal, during which each article was evaluated based on its methodological soundness, clarity of objectives, coherence of findings, and contribution to the field. The evaluation process was carried out by two

independent reviewers to minimize subjectivity and ensure inter-rater reliability. Any disagreements regarding inclusion were resolved through discussion and consensus.

Throughout this process, a reference management tool was used to organize citations and facilitate systematic documentation of reviewed studies. This allowed for easier tracking of duplicates, ensuring that each piece of literature was uniquely analyzed and reported. Studies were then categorized thematically based on their focus, such as technological innovations, regulatory frameworks, stakeholder perspectives, and implementation barriers. These categories formed the basis for the thematic synthesis presented in the results and discussion sections.

In conclusion, the methodological approach adopted in this study is grounded in systematic and rigorous principles that are essential for conducting a credible and insightful literature review. By employing advanced keyword search techniques, establishing strict inclusion and exclusion criteria, and adopting a structured selection process, the study ensures that the literature reviewed is both relevant and academically robust. This methodological rigor enhances the reliability of the findings and contributes meaningfully to the understanding of green transportation initiatives in a global context.

RESULT AND DISCUSSION

The narrative review synthesized findings from a wide body of literature addressing technological innovations, policy support, sustainable logistics models, consumer behavior, and regional case studies relevant to green transportation. The literature was categorized thematically to analyze the various dimensions contributing to sustainable logistics practices. This section presents the results based on the emergent themes and illustrates the interconnectedness of environmental and operational performance, regulatory drivers, stakeholder behavior, and cross-national comparisons in fostering green logistics.

Green Transportation Technologies and Their Performance The literature overwhelmingly points to electric vehicles (EVs), hydrogen fuel cells, biodiesel systems, and smart logistics technologies as the most studied and implemented green transportation solutions. Electric vehicles, in particular, have emerged as a cornerstone of sustainable urban logistics due to their operational cost-effectiveness and low emissions. Research by Andaloro et al. (2015) underscores the ability of electric delivery trucks and buses to improve last-mile delivery while mitigating urban air pollution. Similarly, Jou et al. (2023) confirmed the reduced environmental footprint of electric two-wheeled vehicles in densely populated cities.

Hydrogen fuel cell technology is especially relevant for heavy-duty transport, offering the benefit of fast refueling and long range. Despite infrastructure barriers, its environmental performance is notable, emitting only water vapor as a byproduct. Yu et al. (2024) and Orji et al. (2019) emphasized its utility in long-haul logistics, provided adequate refueling stations are developed. Biodiesel systems, as a transitional solution, offer ease of integration with existing fleets and significantly lower lifecycle emissions, as reported by Jarašūnienė and Bazaras (2023).

Smart logistics technologies, including the Internet of Things (IoT), predictive analytics, and advanced route optimization algorithms, were identified as pivotal tools to reduce operational inefficiencies. Liu and Ma (2022), as well as Grzesiak and Sulich (2023), found that such technologies help logistics firms cut down emissions and costs by minimizing idle times and fuel consumption. The combination of these technologies contributes to a broader systemic shift toward sustainable logistics.

Empirical evidence strengthens the case for these technologies. For example, EVs lower not only carbon emissions but also total cost of ownership due to reduced fuel and maintenance expenditures. Biodiesel-powered fleets have demonstrated a 15% drop in emissions, while hydrogen trucks show performance on par with electric vehicles but with superior logistical feasibility due to quicker refueling. Smart logistics applications have translated into notable cost reductions and environmental gains through efficient load distribution and route planning.

Sustainable Logistics Models and Their Effectiveness Sustainable logistics models such as multimodal transport, circular logistics, collaborative distribution, and smart logistics are increasingly adopted in various regional and industrial contexts. Multimodal transport systems integrate rail, road, and waterways to optimize freight movement. Balakrishnan and Suresh (2017) documented how combining road and rail transport decreases per-mile emissions and boosts cargo efficiency.

Circular logistics, focusing on reuse and recycling of materials within the supply chain, is proving instrumental in achieving waste reduction goals. Moktadir and Ren (2024) reported that firms adopting circular logistics achieved not only reduced landfill contributions but also a 15% cost reduction through material reuse. Collaborative distribution, involving shared logistics networks, was shown by Jarašūnienė and Bazaras (2023) to lower urban emissions by up to 40% and cut operational expenses by 20%. This model is especially effective in densely populated cities with strict emissions regulations.

Smart logistics solutions, leveraging IoT and data analytics, enable real-time inventory and transport management. Leksana (2024) found that these technologies facilitated emissions tracking and fuel consumption reduction, enhancing both sustainability and transparency. Effectiveness assessments reveal that these models consistently outperform traditional logistics in both environmental and economic metrics.

Policies and Regulations Supporting Green Logistics Policy frameworks at international, national, and local levels have significantly shaped the green logistics agenda. Global agreements such as the Paris Agreement and the UN Sustainable Development Goals provide overarching mandates that stimulate national-level legislation. Terzi and Kula (2024) highlighted the role of Goal 11 in embedding sustainability into urban transportation planning.

At the national level, regulations in the EU compel transportation sectors to integrate low-emission technologies. Orji et al. (2019) showed that these mandates have catalyzed adoption of EVs and hybrid logistics models. Local governments further contribute through the designation of low-emission zones and subsidies for clean technology adoption (Jarašūnienė & Bazaras, 2023).

Regulatory frameworks are found to drive innovation. According to Andaloro et al. (2015), emissions caps and incentive structures have accelerated R&D in green logistics. Operational practices shift accordingly, with firms redesigning logistics networks to meet compliance and cost-saving objectives. Du et al. (2023) confirmed that proactive regulation fosters preemptive innovation and strategic sustainability investment.

Additionally, these policies foster inter-organizational partnerships. Terrada et al. (2020) noted that regulatory requirements often necessitate cooperative networks to pool resources and knowledge. This has created innovation clusters around sustainable logistics, particularly in regions with mature environmental governance.

Consumer Behavior and Digital Innovation in Sustainable Logistics Consumer behavior plays a fundamental role in green logistics adoption. Environmental awareness has risen, particularly among younger demographics who prefer brands with eco-conscious values. Jou et al. (2023) and Yu et al. (2024) both highlighted how consumers are willing to pay a premium for carbon-neutral delivery options. E-commerce firms that offer these choices report improved customer satisfaction and loyalty.

However, convenience remains an important determinant. Andaloro et al. (2015) noted that consumers expect rapid deliveries but are increasingly receptive to slightly delayed shipments if they align with green values. Social media campaigns and peer influence further encourage sustainable choices, as noted by Kong et al. (2024).

Digital innovation enables these consumer-driven shifts. AI enhances route optimization and demand forecasting, reducing inefficiencies. Liu and Ma (2022) showed how AI-based tools can adjust routing in real-time, minimizing delivery mileage. IoT technologies, as shown by Terzi and Kula (2024), increase operational visibility, while blockchain improves transparency, helping consumers verify green claims.

Digital platforms also improve reverse logistics, enhancing sustainability through efficient returns and inventory management (Cheng et al., 2023). The integration of these technologies facilitates the dual achievement of environmental and economic performance, providing a scalable solution for future growth in sustainable logistics.

Case Studies of Successful Green Logistics Implementation Multiple national case studies provide rich insights into the implementation of green logistics. In China, the Green Logistics Development Plan (2013–2020) has laid the groundwork for electrified fleets and charging infrastructure, advancing the nation's carbon neutrality goals (Cheng et al., 2023). Yu et al. (2024) emphasized the role of government support in catalyzing innovation and enterprise-level transformation.

Germany's Mobility Strategy 2030 has prioritized multimodal freight and public transport investments, leading to measurable reductions in road freight emissions and urban congestion. According to Jarašūnienė and Bazaras (2023), this approach integrates stakeholder collaboration and consumer engagement to enhance sustainability.

India's Multimodal Logistics Parks (MMLPs) illustrate a successful fusion of infrastructure, technology, and policy. Balakrishnan and Suresh (2017) documented how these parks, by

integrating road, rail, and port infrastructure, have achieved emission reductions and increased freight efficiency.

Malaysia's approach demonstrates the value of incentive-based adoption. Zailani et al. (2014) observed that policy-driven innovation, coupled with stakeholder collaboration, accelerated the adoption of green technologies in logistics. Lessons drawn from these cases affirm the importance of coordinated policy frameworks, public-private cooperation, and consumer education.

In summary, the literature indicates that green transportation technologies, supported by sustainable logistics models, proactive regulations, evolving consumer behaviors, and digital innovation, are pivotal to transitioning toward sustainable logistics systems. Regional case studies reinforce these findings by illustrating the effectiveness of integrated strategies across diverse contexts. As global logistics continue to evolve, these insights provide a foundation for policymakers, industry leaders, and researchers to further advance sustainable practices.

The present review provides a comprehensive synthesis of the current state of green logistics innovations, drawing from empirical evidence, technological developments, and case-based insights across various regions. By examining the alignment and divergence of findings with existing studies, identifying systemic barriers, and proposing potential solutions, this discussion advances the discourse on sustainable transportation-logistics systems.

Alignment and Divergence of Findings with Previous Studies

The results of this review align closely with prior research in several key areas, especially regarding consumer behavior, the role of digital technologies, and the influence of policy frameworks. Jou et al. (2023) highlighted that younger consumers, particularly university students, are more inclined toward electric vehicle adoption, a trend reaffirmed in this review through the demonstrated preference for green delivery options among environmentally aware demographics. However, the interplay between environmental values and expectations of convenience in delivery services is a dimension that has received limited exploration in previous research. This review provides a more nuanced understanding of how the dual desire for rapid and sustainable service shapes consumer logistics preferences.

On the technological front, the role of digital innovation is consistently emphasized in the literature. Studies such as Yu et al. (2024) acknowledge the transformative impact of AI, IoT, and blockchain on sustainable logistics. This review advances the conversation by showing how these technologies do not merely operate in isolation but interact synergistically to improve sustainability metrics. For example, combining AI's predictive capabilities with IoT's real-time data transmission significantly enhances route optimization and resource allocation—efficiencies not fully captured in earlier fragmented analyses.

Policy influences remain a prominent theme. While Bruzzone et al. (2021) and Usvakangas et al. (2024) have assessed emission-based regulations and urban transport reforms, the current review expands this lens by examining regulatory impacts at multiple levels—international, national, and local—and how they collectively stimulate innovation and collaboration. This broader perspective allows for a more systemic understanding of the policy environment, revealing that while local

regulations (such as low-emission zones) may encourage compliance, national and international frameworks provide the structural reinforcement necessary for long-term transformation.

Lessons from Case Studies

A synthesis of international case studies enriches the review's findings by illustrating how contextual dynamics shape green logistics implementation. The German and Chinese experiences highlight the importance of cohesive, vertically integrated policy frameworks. In Germany, multimodal strategies align with national sustainability targets, while in China, investments in EV infrastructure and government subsidies form a foundational ecosystem for green logistics (Cheng et al., 2023; Yu et al., 2024). These integrated approaches are more effective than fragmented policies observed in less mature regulatory environments.

Similarly, India's Multimodal Logistics Parks (Balakrishnan & Suresh, 2017) and Malaysia's stakeholder-driven adoption of green technologies (Zailani et al., 2014) showcase the role of collaboration. While previous research has acknowledged collaboration's benefits, this review goes further by illustrating that public-private partnerships, when strategically coordinated, can address logistical, financial, and infrastructural constraints in a comprehensive manner.

These examples underscore a key insight: sustainable logistics thrives where strategic policy frameworks, robust infrastructure, and collaborative stakeholder ecosystems intersect. Isolated technological or policy innovations may generate incremental gains, but transformative outcomes require integrated and multi-actor engagement—an aspect often underemphasized in prior studies.

Systemic Barriers Limiting Broader Adoption

Despite promising advances, several systemic barriers impede the widespread adoption of green logistics. Financial constraints remain primary, particularly for SMEs that lack the capital to invest in electric fleets, smart technologies, or sustainable infrastructure. As noted by Jarašūnienė and Bazaras (2023), insufficient access to green funding mechanisms continues to hinder eco-innovation. These financial challenges are compounded by the high initial costs of procurement and the need for long-term investment in training and maintenance.

Infrastructure readiness is another substantial barrier. The absence of charging stations, poor multimodal connectivity, and outdated distribution centers limit the feasibility of implementing green logistics in many regions, particularly in developing economies. While companies operating in cities with advanced infrastructure can more easily transition, those in peripheral or underdeveloped areas remain disadvantaged, thus exacerbating regional disparities in sustainability progress (Cheng et al., 2023).

Institutional inertia also plays a critical role. Orji et al. (2019) pointed out that ambiguous regulatory guidance, inconsistent enforcement, and limited incentives discourage logistics firms from pursuing green alternatives. Moreover, resistance to organizational change and lack of alignment between environmental objectives and core business strategies further deter the adoption of sustainable practices. These institutional factors interact with financial and infrastructural barriers to create a web of constraints that delay meaningful transformation.

Informing Public Policy, Private Sector Strategy, and Cross-Sector Collaboration

The insights from this review have practical implications for public policymakers, corporate leaders, and collaborative networks aiming to foster sustainable transportation-logistics systems. For policymakers, the necessity of cohesive regulatory frameworks is evident. Integrated policy ecosystems, such as Germany's Mobility Strategy or China's national logistics reforms, offer blueprints for synchronizing fiscal incentives, emission targets, and infrastructure investments. Du et al. (2023) stress the importance of aligning financial tools like subsidies and tax relief with strategic planning to stimulate green investments.

Furthermore, stakeholder engagement should be institutionalized in the policy development process. As suggested by Jarašūnienė and Bazaras (2023), inclusive policymaking that incorporates industry feedback, civil society participation, and academic expertise is more likely to yield implementable and impactful frameworks. Institutional coordination mechanisms—such as task forces or innovation councils—can facilitate this multi-stakeholder alignment.

In the private sector, businesses must reconceptualize sustainability as a strategic imperative. Yu et al. (2024) showed that ESG-conscious companies outperform peers on several operational metrics. Firms that adopt sustainability not just as a compliance measure but as a source of innovation and brand differentiation are more likely to succeed in future markets. Andaloro et al. (2015) demonstrated that firms integrating EVs into logistics systems not only reduced emissions but also improved operational efficiency, validating the dual benefits of green investments.

Technology adoption must also be viewed through the lens of interoperability. The combination of AI, blockchain, and IoT offers a robust technological foundation, but integration is key. Without interoperability between systems—across platforms, vehicles, and supply chain actors—the full potential of these technologies remains unrealized. Thus, investments in technology should be coupled with system architecture that enables seamless data sharing and collaborative problem-solving.

Cross-sector collaboration emerges as a central enabler of green logistics. Public-private partnerships should extend beyond infrastructure co-financing to include joint ventures in technology incubation and training. As observed in Malaysia and India, collaborative models yield economies of scale and accelerate adoption through shared risks and rewards. Furthermore, the involvement of academic institutions can drive innovation through research and development, while NGOs and advocacy groups can ensure that social equity considerations are embedded in logistics planning (Alagarsamy & Ramdas, 2024).

Innovation ecosystems that link stakeholders across value chains must also prioritize data governance and knowledge transfer. Cheng et al. (2023) emphasized the value of innovation hubs and digital platforms in disseminating best practices. Such ecosystems can evolve into self-reinforcing networks that propagate sustainability norms and facilitate continuous learning across organizational boundaries.

Finally, the current body of research, including this review, is not without limitations. There is a disproportionate focus on developed regions, with limited empirical data from Africa, Latin America, and parts of Southeast Asia. This geographical skewness restricts the generalizability of findings and limits the understanding of unique contextual challenges in these regions. Moreover, many studies rely on theoretical models or short-term assessments without long-term empirical

validation. Future research should address these gaps through longitudinal studies, comparative regional analyses, and interdisciplinary frameworks that integrate environmental science, economics, and behavioral insights.

By identifying these limitations and offering a roadmap for overcoming existing barriers, this discussion provides a foundation for more targeted and effective strategies to foster the global transition to sustainable logistics systems. It also calls for greater alignment between research, policy, and practice to ensure that the innovations emerging in green logistics translate into widespread and lasting impact.

CONCLUSION

This narrative review has examined the multidimensional landscape of green logistics innovation, encompassing green transportation technologies, sustainable logistics models, policy frameworks, consumer behavior, and global case studies. The findings underscore that electric vehicles, hydrogen fuel cells, biodiesel systems, and digital technologies such as AI, IoT, and blockchain significantly improve operational efficiency while reducing environmental impact. Models like multimodal transport, circular logistics, and collaborative distribution are proving effective in lowering emissions and enhancing logistics performance across diverse contexts.

The review reaffirms the urgency of transitioning toward sustainable logistics in response to the logistics sector's disproportionate carbon footprint. However, systemic barriers remain, particularly financial constraints, infrastructural inadequacies, and institutional fragmentation. Overcoming these challenges requires integrated public policies that align regulatory measures with financial incentives, as well as strategic private sector investments in green technologies and collaborative networks.

Policymakers are urged to design comprehensive regulatory frameworks, while logistics providers are encouraged to embed sustainability into their core strategies and invest in interoperable technological systems. Cross-sector collaborations should also be intensified to foster innovation ecosystems and shared infrastructure.

Future research must address geographical gaps, particularly in developing regions, and focus on long-term empirical validation of green logistics strategies. Additionally, integrating interdisciplinary perspectives will enhance understanding of behavior, governance, and technological adaptation. Emphasizing smart logistics and stakeholder engagement as central strategies can accelerate the shift toward greener systems and achieve both environmental and economic resilience in the logistics sector.

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