International Journal of Commerce and Management Research
www.managejournal.com
ISSN: 2455-1627
Received: 09-04-2026, Accepted: 10-05-2026, Published: 25-05-2026
Volume 12, Issue 2, 2026, Page No. 167-173

Transforming logistics and supply chains through artificial intelligence: A comprehensive review

Amitesh Edpache[1], Sukanta Kumar Baral[2]
[1] Research Scholar, Department of Commerce, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh. India
[2] Professor, Department of Commerce & Dean, Faculty of Commerce and Management, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh, India
Corresponding Author: Sukanta Kumar Baral

Abstract
The growing importance of reverse logistics in supply chain management has been driven by the rise of e-commerce, increasing return rates, and the urgent need for sustainable practices. With the global reverse logistics market projected to reach USD 958.3 billion by 2028, businesses are turning to advanced technologies to manage returns efficiently, minimize waste, and reduce environmental impact. This paper reviews how technologies like Artificial Intelligence (AI), automation, and smart logistics systems are improving reverse logistics and helping companies build more sustainable supply chains. AI helps businesses predict how many returns they'll have, manage warehouses better, and track products in real time. In addition to this, technologies like drones, self-driven vehicles, and e-platforms are enabling logistics quick and highly-automated. Along with this circular economy is also get supported by these technologies, which could minimize global waste by 45% among the electronics, textiles, and plastics sectors. The adoption and effective implementation of these technologies in reverse logistics can be evaluated using the Technology Organization Environment (TOE) framework. While the benefits are satisfying, including enhanced operational efficiency, cost reductions and environmental gains along with these, challenges exist, such as cybersecurity risks, high incorporation costs, aligning complexities and the need for skilled personnel. This paper discusses both the opportunities and barriers associated with technology adoption in reverse logistics, guided by the TOE framework, to provide insights for businesses aiming to create more efficient and sustainable supply chains.

Keywords: Logistics, artificial intelligence (AI), automation, smart logistics systems, circular supply chain models, reverse logistics, supply chain management, TOE model

Introduction

The growing emphasis on environmental sustainability, combined with the rapid expansion of e-commerce and heightened customer expectations, has made reverse logistics a critical area of focus within supply chain management (SCM). In order to fulfill both economic and environmental objectives, reverse logistics includes the procedures linked to the return, reuse, recycling and proper disposal of commodities and materials. The requency of product returns has increased dramatically in the digital age, especially in the online retail, prompting businesses to look for ore effective ways to handle returns and minimize waste (Rogers & Tibben-Lembke, 2001; Govindan *et al.*, 2015) [17, 34].

Due to its increasing strategic significance, the worldwide reverse logistics market, which was valued at approximately USD 635.6 billion in 2020[22], is expected to increase significantly, reaching USD 958.3 billion by 2028 at a 5.6% CAGR (Allied Market Research, 2022) [31]. The growth of the e-commerce sector, recalls in the automobile and pharmaceutical industries, and the move towards circular economy concepts that include recycling, reuse and remanufacturing are all contributing reasons. This rising trend forces companies to use cutting-edge technology like automation, artificial intelligence and smart logistics systems to maximize return operations, increase resource efficiency and reduce the environmental impact of logistics related operations (Kumar *et al.*, 2020) [19]. By helping companies move toward more circular supply chain models, these technologies are not only improving operational performance but also supporting more general sustainability goals (Geissdoerfer *et al.*, 2017) [16].

AI is being used extensively to forecast return volumes, utilize warehouse operations and provide real-time product tracking (Wamba Taguimdje *et al.*, 2020) [44]. Drones, self-driving cars and robotics are examples of automation technologies that speed up the handling, shipping and sorting of returned items, minimizing human error and increasing turnaround times (Baryannis et al., 2019) [7]. Digital platforms provide centralized solutions for customer communication, return coordination and data analytics, all of which are essential for developing flexible and responsive logistics networks (Chopra & Meindl, 2019) [10].

The integration of these technologies supports the broader vision of a circular economy, which aims to minimize waste and maximize the value extracted from products and materials. The Ellen MacArthur Foundation (2016) [12] suggests that effective adoption of circular logistics practices could reduce global waste by up to 45% and generate multi-billion-dollar benefits, particularly in sectors such as electronics, plastics, and textiles.

Despite these advantages, several challenges persist. High implementation costs, cybersecurity vulnerabilities, and a lack of skilled human capital are significant barriers to widespread technology adoption (Queiroz *et al.*, 2022) [28]. To navigate these issues, businesses must not only invest in infrastructure and training but also adopt strategic change management approaches that align workforce capabilities with evolving technological demands.

This paper explores the emerging technologies in enhancing reverse logistics, focusing on both the opportunities and obstacles they present and structures the analysis explicitly through the Technology-Organization-Environment (TOE) framework (Tornatzky & Fleischer, 1990) [42]. By doing so, it provide a theoretically grounded, scientifically justifiable examination of adoption factors, benefits, challenges and implications. This paper is based on systematic reviews, bibliometric analyses and empirical studies published up to 2025 to ensure recent trend and rigor.

Literature Review

1. AI applications, Survey and Transformative Impacts in Supply Chain Management

Artificial Intelligence (AI) has emerged as a pivotal technology in transforming business operations, offering the capacity to enhance productivity, improve decision-making, and drive innovation across industries. Its ability to recognize complex patterns, adapt to dynamic environments, retrieve relevant information intelligently, and process large volumes of data in real time makes it an indispensable tool for modern enterprises. In the realm of logistics and supply chain management (L&SCM), AI is increasingly being leveraged to achieve significant improvements in both operational efficiency and strategic foresight. As supply chains become more complex, globalized, and vulnerable to disruptions, AI offers powerful solutions to streamline processes, mitigate risks, and foster agile, data-driven decision-making.

The advent artificial intelligence (AI) and intelligent automation has fundamentally reshaped supply chain management (SCM) by enabling real-time information flow, predictive capabilities, and operational excellence amid increasing global volatility. Shamsuddoha *et al*. (2025) [36] conceptualized AI-driven systems via integrating Machine Learning (ML), Robotic Process Automation (RPA) and advanced analytics as mechanisms that replace conventional human-centric processes with autonomous, resilient operations spanning sourcing to delivery. Their thematic synthesis of 383 peer-reviewed studies (2017-2024) [15, 16] underscored how these technologies facilitate instantaneous decision-making, demand forecasting accuracy, logistics optimization and warehouse efficiency while mitigating risks through proactive disruption prediction. This aligns with broader Industry 4.0 paradigms, where AI fosters agile, data-driven ecosystems that enhance resilience and profitability (Daios *et al*., 2025; Eyo-Udo, 2024) [11, 14].

Demand forecasting and predictive analytics emerge as core conceptual pillars, transforming reactive inventory practices into proactive, precision-oriented strategies. AI algorithms leverage big data, consumer trends and external signals to reduce forecast errors by 20-50%, enabling automated replenishment and minimized stock levels (Adesoga *et al*., 2024; Mishra and Pradhan, 2025). Vudugula (2025) [1, 21], in a PRISMA-guided review of 77 studies, extended this to sustainable contexts, demonstrating how AI integrates with Internet of Things (IoT) for real-time visibility and blockchain for transparent procurement, yielding cost reductions in 52 studies and emissions savings via renewable-energy logistics. Similarly, Raychowdhuri (2025) [30] highlighted distributed processing pipelines and reinforcement learning in retail and operations planning, achieving 15-25% operational cost savings and 20-30% inventory reductions across organizations like Amazon and Walmart.

2. Circular Supply Chain Models

Building directly on AI's forecasting and utilizing capabilities, circular supply chain models represents a natural evolution towards sustainability within Supply Chain Management (SCM). By focusing on the ongoing use of resources through techniques including sharing, leasing, reusing, repairing, refurbishing and recycling, the circular economy deviates from the traditional linear "take-make-dispose" model. When this idea is applied to supply chains, it forms a network that is intended for resource recovery, product return, regenerative flows, and value creation in addition to product delivery (De Angelis *et al*., 2016; Geissdoerfer *et al*., 2018).

By framing circular economy supply chains as a strategic extension of circular economy principles and emphasizing changes from product ownership to access-based models, structural flexibilities for localized loops, coexistence of open and closed material cycles, cross-sector collaboration and procurement as levers for scaling circular business models, De Anhelis *et al*. (2016) [12] laid the groundwork. Geissdoerfer *et al*. (2018) further developed a conceptual framework identifying multiple circular loops-closing (recycling/reuse), showing (product-life extension), intensifying (higher utilization), narrowing (reduced material input), and dematerializing (service-based alternatives) that require reconfiguration of logistics networks and stakeholder value perceptions.

Artificial Intelligence and automation serve as critical enablers of these circular models. Meena *et al*. (2025) [21] aligned circular Supply Chain Management (SCM) with Society 5.0 principles, demonstrating how AI-driven demand forecasting, real-time inventory monitoring, predictive quality control, efficient return processing and lifestyle sustainability reporting minimize waste and support regenerative flows. Therefore, AI-enabled automation and logistics close the gap between circularity and smart operations, turning reverse logistics into a value-adding process that improves social, economic, and environmental performance (Vudugula, 2025; Sun *et al*., 2022; Rodrigues *et al*., 2025) [33, 40, 43].

3. Smart Logistics Systems

Smart logistics systems, which combine cutting-edge data science technologies with contemporary logistical infrastructure to achieve increased automation, efficiency and adaptability, operationalize the integration of AI and automation into circular supply chain management. These systems combine blockchain, IoT, AI, big data analytics and machine learning to provide autonomous execution, intelligent-decision-making and real-time data collecting (Ding *et al*., 2020; Chung, 2021).

Ding *et al*. (2020) synthesized IoT-enabled smart logistics across freight transportation, warehousing and delivery, emphasizing real-time tracking, predictive maintenance, route optimization and dynamic inventory management. In addition, Chung (2021) evaluated optimization models for fleet management, warehousing automation, traffic flow and predictive analytics while advocating for flexible, decentralized methods to deal with disturbances. Smart logistics thus acts as the technological backbone that makes AI-driven circular supply chains feasible, linking forward and reverse flows through seamless visibility and responsiveness (Mishra & Pradhan, 2025; Shamsuddoha *et al*., 2025) [21].

4. Automation in Logistics and Supply Chain Management

The execution layer of AI applications in SCM and smart logistics systems is automation. In order to increase efficiency, accuracy and resource utilization while lowering human error, it refers to the methodical deployment of robots, robotics and software to carry out repetitive, time-consuming operations including sorting, packaging, inventory control and order fulfilment (Andiyappillai, 2020; Nitsche *et al*., 2021) [23].

Empirical evidence from Andiyappallai (2020) illustrate tangible gains in internal coordination, cost reduction, error minimization and cross-functional collaboration following automation adoption in logistics firms. Nitsche et al. (2021) [23] provided a holistic framework identifying ten application domains (warehouse automation, material handling, order fulfillment, transport optimization etc.) and ten critical antecedents (system integration, data availability, organizational culture, leadership support, knowledge management) that determine automation success. When combined with AI, automation enables the phased RPA-to-AI integration highlighted by Shobana and Vjay Raja (2025) [38], delivering 24.8% cost reductions, 21.3% shorter lead times, and 52.6% fewer errors-outcomes that directly support both smart logistics performance and circular supply chain loops.

Theoretical Framework: the TOE Model

The technology-Organization-Environmental (TOE) framework, introduced by Tornatzky and Fleischr (1990) [42], provides the overarching theoretical lens for understanding the adoption of AI, automation and smart logistics technologies within circular SCM. Unlike user-centric models such as the Technology Acceptance Model (TAM), TOE is an organization-level framework ideally suited to complex supply chain innovations. It posits that technology adoption decisions are shaped by three interconnected contexts:

1. **Technological:** which incorporate the compatibility, complexity, observability and relative advantage.
2. **Organizational:** which incorporate the size, readiness, slack resources, innovativeness of the firm and the top-management support.
3. **Environmental:** which incorporate the competitive pressure, customer or supplier demands, industry norms and regulatory framework/environment.

Empirical applications of Toe have consistently shown that these three aspects explain 40-60% of variance in adoption outcomes for green supply chain practices (Hwang *et al*., 2016) [18], blockchain in emerging market supply chains (Chittipaka *et al*., 2023) [9] and Industry 4.0 technologies in reverse logistics (Rahim *et al*., 2024) [29]. In the present study, TOE serves as the integrative framework linking AI-driven smart logistics and automation (technological and organizational factors) with the broader imperatives of circular supply chain models (environmental and sustainability pressures), thereby explaining both the enablers and barriers to transformative adoption in logistics and SCM.

Collectively, the synthesized literature illustrates a coherent progression that is AI and automation powered smart logistics systems, which in turn operationalize the circular supply chain models, all of which can be systematically examined through the TOE framework. This integrated perspective underscores the strategic necessity of leveraging intelligent technologies to build resilient, sustainable and efficient supply chains in an increasingly volatile global environment.

Objectives of the Study

It aims to offer insights into how companies can build more efficient, resilient, and sustainable supply chains through the adoption of smart logistics solutions.

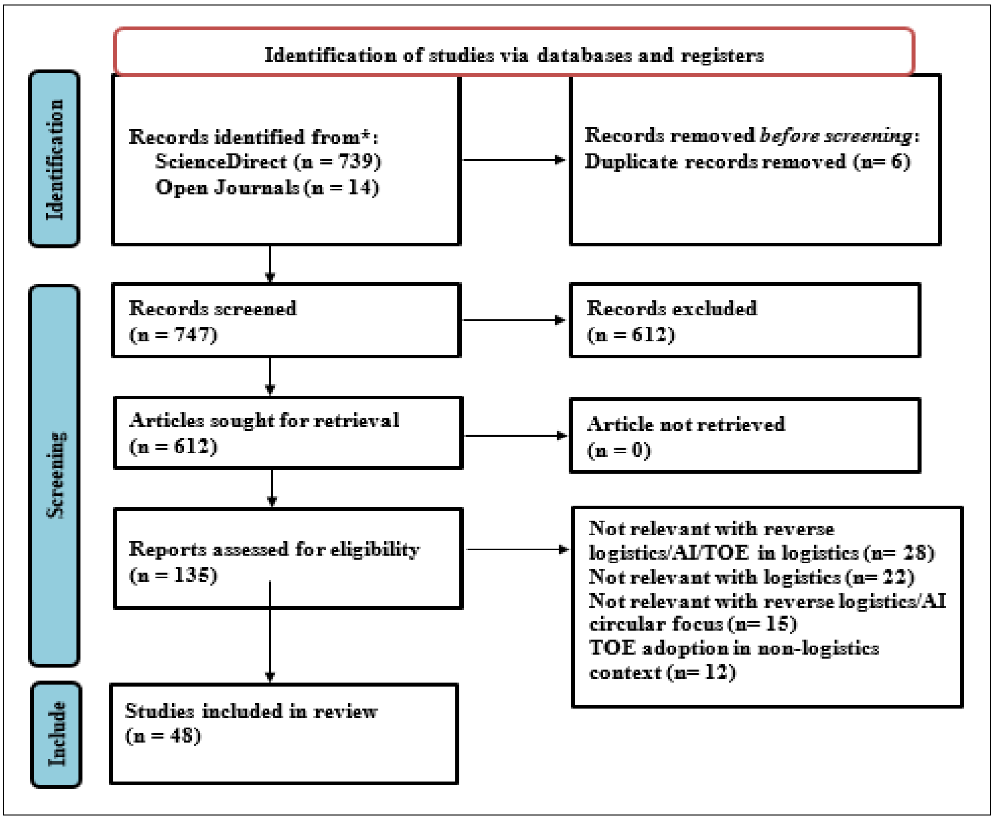
1. To carry out a comprehensive literature review to analyze the current state of supply chain management.
2. To understand the effectiveness, benefits, and advantages of integrating AI into supply chain and logistics management.
3. To identify the key challenges and limitations involved in implementing AI, automation, smart logistics systems, and circular supply chain models within supply chain management.

These objectives aim to provide valuable insights into how businesses can effectively leverage AI-driven solutions to enhance operational efficiency, improve customer satisfaction, and sustain a competitive advantage in the rapidly evolving logistics industry.

Research Methodology

This study adopts a systematic literature review (SLR) combined with bibliometric analysis to examine the role of Artificial Intelligence (AI), automation, smart logistics systems and circular supply chain models in transforming reverse logistics and sustainable supply chain management. The SLR follower the PRISMA guidelines to ensure transparency, reproducibility and rigor.

Peer-reviewed articles were retrieved from three major databases – ScienceDirect and open journals using a structured search string that combined keywords such as "reverse logistics," "circular supply chain," "industry 4.0/5.0" and "TOE framework." The search criteria focused on empirical, conceptual and review studies explicitly addressing technology adoption in logistics or supply chains, while exclusion criteria eliminated non-peer-reviewed sources, conference abstracts and studies unrelated to sustainability or reverse supply chain.



Source: Author's Own Compilation

Fig 1: PRISMA Statement 2020

After removing duplicates and screening titles, abstracts and full texts, the final compilation include high-quality sources) that informed both narrative synthesis and bibliometric mapping. Keyword co-occurrence analysis was performed using VOSviewer software (version 1.6.20) to visualize the intellectual structure of the field and identify thematic clusters around sustainability, digital transformation, AI, and Industry 4.0/5.0. Thematic analysis was guided by the Technology Organization Environment (TOE) framework to organize findings into technological, organizational and environmental contexts. This hybrid approach ensures a comprehensive, up-to-date and theoretically grounded synthesis of the literature.

Results and Findings

1. Technological Context

Technological factors determine perceived usefulness and ease of integration. Artificial intelligence and machine learning offer clear relative advantage in predictive accuracy like neutral networks forecast end-of-life product returns with Mean Absolute Percentage Error (MAPE) reductions of 15-30% (Silva *et al*., 2025) [39]. Compatibility with existing ERP/WMS systems is high when using cloud-based platforms, through complexity including data integration and algorithm opacity, remains a challenge.

Internet of Things (IoT) and blockchain real-time tracking and immutable records, reducing fraud in returns (Chittipaka *et al*., 2023) [9]. Drones and Automated Vehicles provide advantages in speed and cost for reverse transportation: autonomous systems optimize routes, fuel usage reduction by 20-40% and enable circular flows by collecting recyclables in route (Odumbo & Onuma, 2025) [24]. Trialability is facilitated by pilot programs such as Amazon drone returns testing). Overall, these technologies align well with reverse logistics' need for speed, accuracy and traceability, provided interoperability challenges are addressed.

2. Organizational Context

Internal readiness is important. Large firms with much slack resources and IT infrastructure adopt faster (Chittipaka *et al*., 2023) [9]. Allocating budgets for artificial intelligence training and infrastructure by the top-level management, is the strongest predictor in multiple studies (β = 0.41 in blockchain supply chain management research). Organizational innovativeness and skilled workforce readiness determine success in integrating artificial intelligence for warehouse optimization or automatic vehicle fleets.

Smaller firms often lag due to limited capital and change-management capacity. Successful adopters invest in upskilling cross-functional teams combining logistics experts with data scientists. Examples include e-commerce giants using AI-driven sorting robots, achieving 99% diversion from landfills in pilot returns programs.

3. Environmental Context

External pressures accelerate adoption. Regulatory mandates such as European Union's Extended Producer Responsibility (EPR) and sustainability reporting requirements push circular economy practices (Hwang *et al*., 2016) [18]. Competitive intensity like rival's offerings faster, greener returns that creates mimetic pressure. Customer demands for transparent, eco-friendly returns and supplier collaboration including shared blockchain platforms, further drive adoption.

In growing markets, government's incentives for green logistics amplify environmental aspect effects (Chittipaka *et al*., 2023) [9]. Industry norms towards net-zero supply chains amplify these forces, making TOE particularly explanatory for reverse logistics.

Benefits and Support for the Circular Economy

TOE-aligned adoption provide measurable gains. An accurate return-volume assessment and automated segregation is done through enabling artificial intelligence or machine learning, minimizing 30-50% of time taken in processing and foster remanufacturing (Bhowmik *et al*., 2024; Silva *et al*., 2025) [1, 39]. Automation and smart systems improve warehouse efficiency, while drones and automatic vehicles cut the last-mile reverse logistics costs and emissions by upto 50% (Odumbo & Onuma, 2025) [24].

Collectively, these technologies advance circular economy principles by making materials' use longer, minimized waste and the value is recaptured. Real-world pilots demonstrate upto 70% waste diversion in returns operations and significant CO_2 reductions (industries case studies aligned with Ellen MacArthur Foundation principles). In electronics, textiles and plastics, reverse logistic technologies enable closed loops that save billions in non-used material costs while cutting global waste streams that directly supporting the 45% scale reduction referenced in broader sustainability projections through systematic efficiency gains.

Challenges and Barriers

In spite of the above benefits, TOE framework highlights constant hurdles

- **Technological:** Cybersecurity vulnerabilities in Internet of Things (IoT)/ blockchain systems and integration complexity with legacy infrastructure.
- **Organizational:** High upfront costs (AI platforms, automated vehicle fleets) and skill gaps among the users resulting global cybersecurity and digital talent shortages, which is projected to reach millions by 2030.
- **Environmental:** Regulatory fragmentation across jurisdictions and competitive pressures that favor short-term cost saving over long-term sustainability investments.

Additional barriers include data privacy concerns, public acceptance of drones or automated vehicles and the need for workforce re-skilling (Odumbo & Onuma, 2025) [24]. These challenges explain slower adoption in SMEs and developing regions.

The pictorial network visualization reflects the intellectual structure of research at the intersection of digital transformation, artificial intelligence (AI), industry 4.0/5.0, and sustainability. Central intersection such as sustainability, digital transformation, artificial intelligence and industry 4.0 demonstrate their critical role in connecting diverse themes. Technology adoption including Internet of Things (IoT), Artificial Intelligence and Blockchain adoption; circular economy, decarbonization and machine learning applications create a strong cluster. The map highlights how growing technologies are increasingly investigated as enablers of green innovation, supply chain resilience and energy efficiency, particularly in the context of climate change and industry 5.0. This co-occurrence network highlights the growing convergence between digitalization and sustainable development goals.

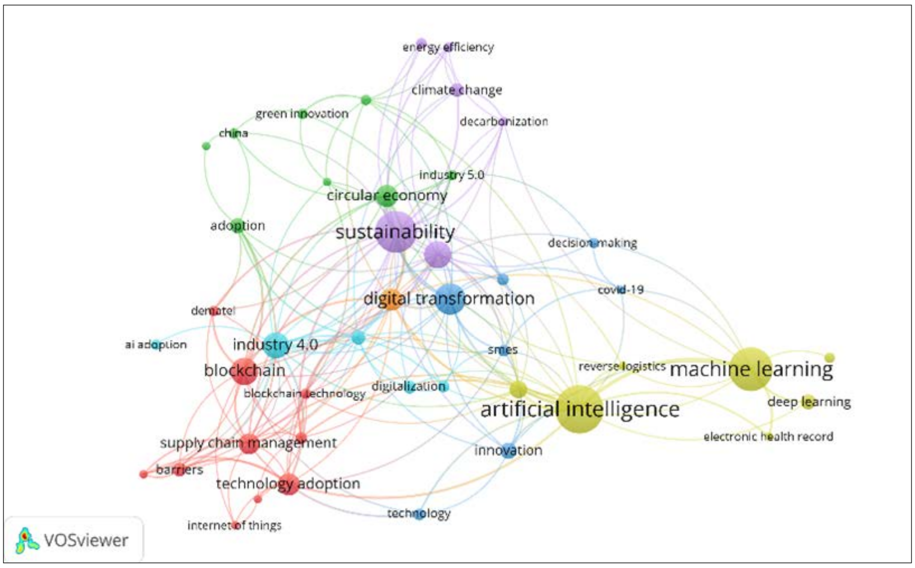


Fig 2: Keywords in published literature using VOSviewer

Conclusion

This study gives an idea that the integration of Artificial Intelligence, automation, smart logistics systems and circular economy principles has the potential to fundamentally transform reverse logistics from a cost center into a strategic driver of sustainability and competitive advantage. Guided by the Technology Organization Environmental (TOE) framework, the review reveals that technological advancements such as predictive analytics, real-time tracking and autonomous systems significantly improve return processing efficiency, reduce waste and support closed-loop supply chains. These benefits, however, materialize only when organizations processes sufficient internal readiness and respond effectively to external pressures such as regulatory mandates and shifting customer expectations.

The findings reinforce that successful technology adoption in reverse logistics is not merely a technical exercise but a complex interplay of technological capabilities, organizational commitment and environmental forces. While the opportunities for cost reduction, emission savings and resource recovery are substantial, challenges related to high implementation costs, skill gaps, cybersecurity risks and resistance to change remain critical barriers, particularly for small and medium enterprises.

Ultimately, businesses that strategically balance advanced technologies with human-centric approaches through continuous workforce upskilling, ethical governance and change management; will be better positioned to build resilient and sustainable supply chains.

Future research should focus on empirical validation of the extended TOE framework (incorporating sustainability as a separate context), sector-specific longitudinal studies and the role of developing technologies such as generative AI in reverse logistics decision-making. By bridging these gaps, scholars, academicians and practitioners can jointly advance the transition towards truly circular and intelligent global supply networks in an era of heightened environmental accountability.

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