ROLE OF ARTIFICIAL INTELLIGENCE (AI) APPLICATIONS IN SUPPLY CHAIN AND LOGISTICS IN TRANSITION TOWARDS A CIRCULAR ECONOMY

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Abstract

This literature review examines the transformative impact of artificial intelligence (AI) on facilitating the transition of supply chain and logistics systems toward a circular economy (CE). Drawing on a synthesis of recent empirical and conceptual studies, the review identifies key AI technologies, including machine learning, deep learning, natural language processing, and Internet of Things (IoT) devices, and their applications across various CE practices, such as reverse logistics, waste minimisation, green procurement, and ethical sourcing. The findings indicate that AI significantly enhances operational efficiency, predictive capabilities, and resource optimisation, while also addressing environmental challenges through improved transparency and automation. Furthermore, the review highlights how the integration of AI with IoT and blockchain technologies enhances material traceability and emission tracking, thereby supporting the design of circular supply networks. Despite these advancements, notable challenges persist, including data silos, high infrastructure costs, and ethical concerns regarding the collaboration between humans and AI. The review also reveals a regional research gap, with limited localised models for developing economies like Sri Lanka. Conclusively, the study calls for multi-stakeholder collaboration, improved regulatory frameworks, and empirical validations to harness AI's full potential in achieving sustainable and circular logistics systems.

Keywords: Artificial intelligence, circular economy, green supply chain, supply chain management, smart logistics

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Introduction

The global push toward sustainable development and environmental stewardship has positioned the circular economy (CE) as a vital strategy for reducing resource consumption, minimising waste, and enhancing operational resilience. At the heart of this transformation lies artificial intelligence (AI), a disruptive technological force revolutionising supply chain and logistics management. Over the past decade, AI has evolved from a promising innovation into a critical enabler of intelligent, data-driven decision-making across supply chain functions. Its integration has facilitated predictive analytics, real-time monitoring, autonomous routing, and lifecycle product tracking, aligning logistics operations with the principles of a circular economy. Technologies such as machine learning, computer vision, natural language processing, the Internet of Things (IoT), blockchain, and digital twins are now redefining core logistics processes, including demand forecasting, defect detection, predictive maintenance, and circular product traceability. However, despite these advances, several barriers hinder the widespread adoption of AI in CE-focused supply chains. These include high implementation costs, limited data availability, skills shortages, organisational resistance, ethical and regulatory concerns, and fragmented digital infrastructures, particularly prevalent in developing contexts such as Sri Lanka. As industries navigate this digital shift, understanding the role of AI, the tools involved, and the challenges faced is crucial for accelerating the transition toward circular, intelligent, and sustainable logistics ecosystems.

Objectives

This review aims to systematically analyse the existing body of literature concerning the role and impact of AI applications in logistics and supply chain management, with a particular focus on their contribution to the transition towards a circular economy. The objectives are as follows: To identify and classify the key AI applications used in supply chain and logistics operations.

RO1: To identify and classify the key AI applications used in supply chain and logistics operations.

RO2: To investigate the barriers and challenges faced in adopting AI technologies for circular economy-focused supply chain transformation.

RO3: To identify and examine the key characteristics of circular economy practices

RO4: To analyze the observed environmental and operational impacts of AI adoption in supply chains transitioning toward circular models.

RO5 To identify gaps in the existing literature and propose future research directions for AI-driven circular supply chain development.

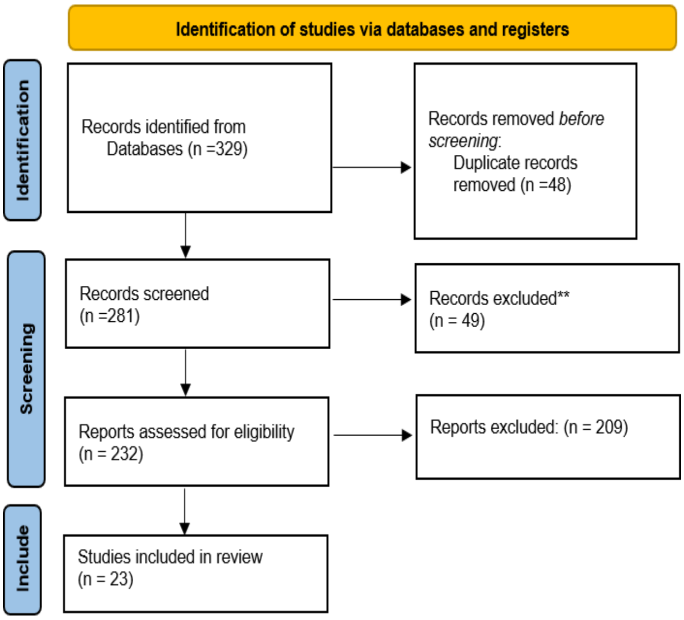
Methodology

This study employs a Systematic Literature Review (SLR) approach, guided by the PRISMA 2020 framework, to investigate how AI supports the transition of supply chain and logistics systems toward a CE. The review ensures transparency, reproducibility, and comprehensive coverage by following a structured multi-stage process. Targeted Boolean search queries using keywords such as 'AI in logistics', 'circular economy', and 'reverse logistics' were executed across databases, including ScienceDirect, IEEE Xplore, SpringerLink, Emerald Insight, Taylor & Francis, and Google Scholar, focusing on peer-reviewed studies published between 2015 and 2024. This yielded 328 records, from which 48 duplicates were removed. A title and abstract screening of the remaining studies reduced the count to 232. After applying the inclusion criteria, 23 peer-reviewed studies were selected for final analysis, meeting the criteria of relevance to AI in supply chains, CE focus, and recency criteria. Each study was read in full, annotated, and coded using an open thematic coding strategy, allowing emergent patterns and relationships to be captured without conducting a quantitative meta-analysis due to the heterogeneous study designs. The PRISMA framework ensured systematic tracking and reporting at every stage of the review. Ultimately, this rigorous methodology lays a strong foundation for mapping AI applications, identifying research gaps, and proposing conceptual frameworks that support circular supply chain transformation, particularly in developing contexts like Sri Lanka.

Results and Discussion

The review of 23 academic studies highlights the transformative role of Artificial Intelligence (AI) in advancing circular economy (CE) practices within supply chain and logistics management. AI tools such as machine learning, predictive analytics, and natural language processing support demand forecasting, reverse logistics, and waste reduction, key enablers of circular systems. Notably, AI aids in end-of-life product recovery and material reuse. Integration with IoT, blockchain, and cloud technologies further enhances transparency, traceability, and real-time decision-making. However, adoption faces barriers, including technical limitations, high implementation costs, lack of expertise, and ethical concerns like data privacy. While most studies emphasise efficiency gains, fewer directly link AI to CE outcomes, revealing a research gap. Nonetheless, findings confirm AI's broader potential in supporting strategic sustainability goals, from eco-design to lifecycle management, pointing to the need for interdisciplinary approaches in future research.

Figure 1
PRISMA flow diagram



(Source: Authors' Compilation)

Thematic Synthesis

Theme 1: To identify and classify the key AI applications used in supply chain and logistics operations.

The review highlights the diverse applications of AI in enhancing supply chain and logistics efficiency while supporting circular economy goals. Key areas include demand forecasting, predictive maintenance, and route optimisation, enabled by technologies such as machine learning, deep learning, and reinforcement learning. AI also drives process automation in smart warehouses, supports risk and disruption management through big data analytics, and improves transparency via blockchain integration. Additionally, tools like Natural Language Processing (NLP) streamline communication and contract management. Collectively, these AI applications help optimise resources, reduce waste, and improve decision-making across the supply chain.

Table 1
Key AI applications across supply chain functions

AI applications	Usage	Key Studies
Machine Learning	forecasting, pattern recognition, and demand	Zhang et al. (2020), Ali & Khan
Deep Learning	Real-time object detection.	Patel & Sengupta (2021), Li et al.
NLP	Text-based document handling.	Rahman & Chowdhury (2023), Kumar & Raj
Computer Vision	Inspection, visual quality	Singh & Tan (2021), Huang et al.
Robotics	Warehouse automation	Miller & Zhou (2020), De Silva et al.
AI-enabled Decision Support	Strategic & tactical decision	Chen & Liu (2018), Perera et al.
Multi-Agent Systems	Coordinated decision making	Ghosh & Sen (2019), Bui & Ha (2020)
Digital Twins	Virtual simulations for the process	Wang & Zhu (2023), Nanayakkara et al.
Blockchain + AI	Secure, traceable decision	Fernando & Silva (2022), Rai et al.
Data Mining	Pattern discovery from large	Chakraborty et al. (2019), Weerakoon & Fernando
Route Optimization	Optimising delivery paths, minimising fuel	Kim et al. (2021), Rathnayake & Zaman
Process Automation	Repetitive task execution	Jayasuriya & Gomez (2023), Nadeesha & Kumar
Demand Forecasting	Anticipating demand trends for inventory	Lim & Choi (2020), Wijesekara & Ranaweera (2022)
Predictive Maintenance	Failure prediction, maintenance	Wickramasinghe et al. (2021), Balamurugan & Rao (2022)

(Source: Authors' Compilation)

Theme 2: To investigate the barriers and challenges faced in adopting AI technologies for circular economy-focused supply chain transformation.

The literature identifies a network of systemic and organisational barriers constraining the adoption of Artificial Intelligence (AI) in circular economy (CE)-oriented supply chains. A central issue is the high upfront investment in infrastructure, such as IoT devices, machine learning platforms, and cloud architecture, which disproportionately affects small and medium-sized enterprises (SMEs), particularly in developing economies (Wang, 2021; Boute & Udenio, 2021; Mahmood et al., 2022). This financial burden is compounded by a scarcity of skilled professionals in AI engineering, data science, and systems integration, resulting in implementation failures and underutilization of technology (Onukwulu et al., 2024; Bhowmik et al., 2024).

Beyond technical readiness, many organisations face challenges related to data fragmentation and legacy system incompatibility, particularly with ERP and warehouse management systems (WMS), which obstruct AI deployment and cause costly operational disruptions (Al Doghan & Sundram, 2023). Cybersecurity concerns and regulatory uncertainty further inhibit adoption due to fears of data breaches and non-compliance (Dubey et al., 2023). From a socio-organisational perspective, resistance to change is prevalent, often rooted in job displacement anxiety and a lack of clarity regarding leadership's vision for AI's role in CE transitions (Agrawal et al., 2018; Hao & Demir, 2024). Ethical challenges, including algorithmic bias and a lack of transparency, also pose risks to the equitable deployment of AI (Dauvergne, 2020). These issues align with the Technology-Organisation-Environment (TOE) framework, which posits that innovation adoption is contingent not only on technical capacity but also on institutional pressures and organisational inertia.

Theme 3: To identify and examine the key characteristics of circular economy practices.

The reviewed studies identify ten key ways AI enables circular economy (CE) practice in supply chain and logistics. AI supports waste reduction, predictive maintenance, reverse logistics, eco-design, and emission tracking. It also enhances transparency through blockchain, real-time monitoring via IoT, and automates disassembly with smart robotics. Additionally, AI facilitates stakeholder collaboration and the development of secondary markets for recycled goods. Overall, AI acts as a powerful driver of sustainability and resource efficiency in circular supply chains.

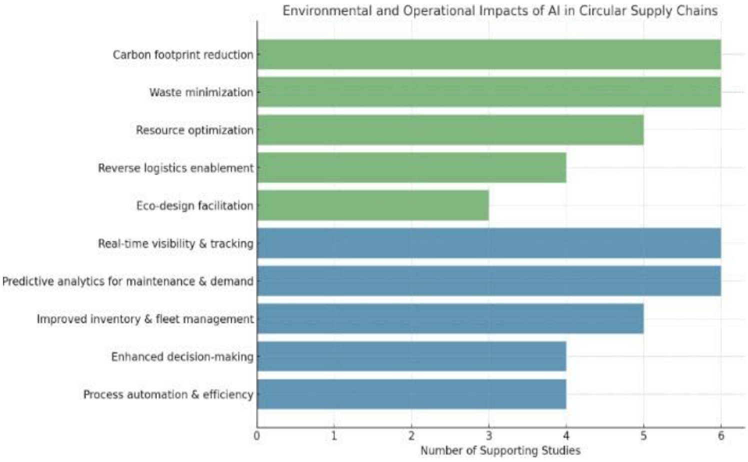
Table 2
Key Circular Economy Characteristics and the Role of AI in Enabling Sustainable Supply Chain

Circular Economy Characteristics	Usage in SCM/Logistics	Example Studies
Resource Efficiency and Waste Minimisation	AI optimises resource use and reduces waste through real-time monitoring and smart inventory management.	Bhattacharya et al. (2024); Dubey et al. (2023)
Product Life Extension	AI supports predictive maintenance and condition monitoring to extend asset lifespan.	Bhowmik et al. (2024); Ernst et al. (2019)
Reverse Logistics and Closed-Loop Systems	AI enables intelligent return routing and reprocessing systems, optimising remanufacturing loops.	Wang (2021); Mahmood et al. (2022)
Eco-Design and Green Packaging	AI supports sustainable product design and packaging decisions based on recyclability and minimal material usage.	Shinde & Phadke (2023); Hao & Demir (2024)
Sustainable and Ethical Sourcing	AI and blockchain monitor environmental and ethical compliance in supplier networks.	Dubey et al. (2023); Onukwulu et al. (2024)
Digitalisation and Intelligent Systems	Digital twins, AI, and IoT optimise operations and improve sustainability insights.	Shuaiqi Wang (2021); Boute & Udenio (2021)
Collaboration and Multi-Stakeholder Engagement	AI platforms enhance coordination and data sharing between circular economy stakeholders.	Bhowmik et al. (2024); Shinde & Phadke (2023)
Design for Disassembly and Material Recovery	AI aids in creating modular designs and guides automated disassembly for raw material recovery.	Agrawal et al. (2018)
Carbon and Environmental Footprint Reduction	AI tools track emissions and optimise transport to reduce environmental impact.	Dauvergne (2020); Hao & Demir (2024)
Economic Value Creation from Waste	AI evaluates waste for upcycling and finds market value in secondary materials.	Mahmood et al. (2022)

(Source: Authors' Compilation)

Theme 4: To analyse the observed environmental and operational impacts of AI adoption in supply chains transitioning toward circular models.

Figure 2
Distribution of Environmental and Operational Impacts of AI in Circular Economy-Oriented Supply Chains Based on Literature Evidence



(Source: Authors' Compilation)

A growing body of literature confirms that the adoption of AI in circular economy (CE)-oriented supply chains promotes both environmental sustainability and operational excellence. Environmentally, AI contributes to resource efficiency by enabling predictive maintenance and real-time monitoring, thereby extending product life cycles and reducing material waste (Rajabion et al., 2022; Farshadfar et al., 2024). For example, in reverse logistics, AI-powered systems enhance the precision of remanufacturing and recycling decisions, improving material recovery outcomes (Ramadoss, 2021). Additionally, AI supports emission tracking and eco-friendly packaging optimisation, functions aligned with CE principles of lifecycle thinking and closed-loop systems (Dubey et al., 2023; Hao & Demir, 2024). From an operational standpoint, AI enhances supply chain agility and resilience through real-time analytics, digital twins, and scenario modelling, all of which reflect the dynamic capabilities framework, the ability of firms to sense, seize, and reconfigure in volatile environments (Teece, 2007). Techniques such as demand forecasting and route optimisation streamline logistics and improve service levels (Onukwulu et al., 2024; Bhowmik et al., 2024). Moreover, interoperability tools facilitate integration across decentralised supply networks, a key enabler of system-wide circularity (Al Doghan & Sundram, 2023).

Theme 5: To identify gaps in the existing literature and propose future research directions for AI-driven circular supply chain development.

The literature on AI in circular supply chains highlights several key gaps. Most studies lack sector-specific insights, with a limited focus on industries such as apparel, agriculture, or electronics. There's also a shortage of research linking AI to measurable circular economy (CE) outcomes, such as resource circularity or reduction in environmental footprint. SMEs and developing regions remain underrepresented, as most frameworks are based on large firms in developed economies. Challenges around system interoperability, real-time responsiveness, and ethical concerns (e.g., algorithmic bias, transparency) are often overlooked. To address these gaps, future research should prioritise industry-specific AI models, standardised CE metrics, low-cost AI solutions for SMEs, the integration of real-time tools like digital twins, and the development of ethical governance frameworks to support equitable and sustainable circular transitions.

Table 3
Future research directions for advancing artificial intelligence integration in circular supply chains and logistics systems

Direction	Description
1. Sector-Specific AI Frameworks	Develop AI integration models tailored to individual industries (e.g., apparel, food, tech), addressing specific CE objectives like waste reduction and closed-loop flows.
2. AI-CE Impact Metrics	Define standardised KPIs linking AI adoption with CE goals such as resource circularity, reuse rates, and lifecycle optimisation.
3. Focus on Low-Income Economies	Investigate localised AI solutions in developing economies with emphasis on affordability, low-bandwidth tech, and mobile-first platforms.

4. Multi-Agent and Real-Time Systems	Explore decentralised AI (e.g., multi-agent systems, digital twins) to enable real-time reverse logistics and waste management decisions.
5. Life-Cycle Environmental Audits	Employ LCA (Life Cycle Assessment) to quantify the environmental benefits and drawbacks of AI integration in circular supply chains.
6. Ethics and Trust in AI	Examine AI transparency, stakeholder trust, data ownership, and greenwashing in circular supply chain AI solutions.
7. Cross-Sector Data Sharing Platforms	Research federated learning or secure AI models that allow data sharing across supply chain actors without compromising privacy.
8. Hybrid Models for Decision-Making	Combine AI with systems thinking, circular business models, and behavioural economics to co-design sustainable SCM practices.

(Source: Authors' Compilation)

Conclusion

This systematic review of 23 peer-reviewed studies confirms that Artificial Intelligence (AI) serves as a critical enabler of circular economy (CE) practices in supply chain and logistics systems. AI technologies such as predictive maintenance, demand forecasting, route optimisation, automated waste sorting, and sustainable sourcing consistently enhance resource efficiency, operational agility, and environmental performance. These tools align closely with CE principles by supporting closed-loop flows, lifecycle optimisation, and real-time decision-making. However, the transition toward AI-driven circular supply chains remains uneven and constrained by multiple barriers. Key limitations include a shortage of skilled talent, fragmented data ecosystems, high implementation costs, and limited infrastructure, which are particularly acute in developing economies like Sri Lanka. Institutional voids such as unclear regulatory guidance, low stakeholder awareness, and organisational resistance further impede adoption. To unlock AI's full potential in circular transformation, a multi-stakeholder approach is essential, combining technological readiness with capacity building, inclusive policy frameworks, and sector-specific innovation pathways. Future research should aim to bridge the gap between AI capabilities and CE outcomes through standardised metrics, ethical governance, and practical models tailored to diverse industry contexts.

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