Leveraging AI-Driven Supply Chain Analytics for Accelerating the Circular Economy: A Focus on Real-Time Resource Management and Extended Product Life-Cycles

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Digital supply chains are increasingly critical to advancing circular-economy models because they couple artificial intelligence (AI), the Internet of Things (IoT) and big-data analytics to provide real-time resource tracking, predictive maintenance and data-driven end-of-life product management. **Purpose –** This article investigates how such AI-enabled analytics accelerate the shift from linear to circular supply chains. **Design/methodology/approach –** A systematic literature review followed by a Summative Content Analysis (SCA) was conducted on eight Web of Science-indexed articles published between December 2024 and March 2025. **Findings –** The evidence shows that integrating AI-based analytics strengthens supply-chain resilience, cuts resource inefficiencies and supports closed-loop flows, provided that organisational capabilities and policy frameworks are in place. **Research implications –** The study consolidates emerging knowledge on the enablers and barriers of AI-driven circular supply chains and proposes future research avenues. **Practical implications –** Managers can leverage real-time analytics to extend product life-cycles and minimise waste. **Originality/value –** This is one of the first reviews to apply SCA to recent empirical work at the intersection of AI, supply-chain analytics and the circular economy.

Keywords:
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1 Introduction

The integration of artificial intelligence (AI) and blockchain in the supply chain, besides contributing to the economic growth of countries («The Visegrad Group and the Industry 4.0», 2020) also enhances its sustainability by improving efficiency, minimizing waste, and ensuring ethical sourcing (Dagou & Gurgun, 2024; Onyeaka et al., 2023; Pap et al., 2025). While blockchain boosts traceability and accountability (Dagou & Gurgun, 2024), AI optimizes resource use and promotes circular economy practices, i.e., reusing, repairing, and recycling materials (Hasan et al., 2023; Liu et al., 2023; Onyeaka et al., 2023). However, not all organizations are ready to implement AI promptly in the face of SC uncertainties (Chowdhury et al., 2025; Rashid et al., 2025), so they must develop capabilities to assess AI's impact on sustainable SC performance, fostering innovative environmental solutions and boosting efficiency and resilience (Barhmi et al., 2024; Chowdhury et al., 2025). This shift requires adopting a circular economy model, which contrasts with the traditional linear "take, make, dispose" approach by prioritizing waste reduction and resource efficiency (Amoah et al., 2022).

This paper hypothesises that AI-driven digital supply chains, real-time tracking and proactive maintenance reduce waste and environmental impact. **The remainder of the paper is structured as follows:** Section 2 reviews the theoretical foundations of supply-chain management and the circular economy; Section 3 details the Summative Content Analysis methodology; Section 4 presents the results; Section 5 discusses practical and theoretical implications; and Section 6 concludes the study and outlines recommendations for future research.

2 Theoretical background

Supply chain

SC covers the process from raw material supply to product distribution, including production, processing, transportation, and distribution (Sutar et al., 2024). Due to the interconnectivity of product components, SCs can quickly become complex and fragile (Hasan et al., 2023), a complexity that underlines the relevance of Industry 4.0 technologies, or “smart manufacturing,” including AI, IoT, and big data analytics, which boost efficiency, flexibility, and agility while mitigating business risks

(Rashid et al., 2025). AI, in particular, strengthens SC's adaptability and resilience to dynamic customer demands (Barhmi et al., 2024; Kusiak, 2023).

Also, servitization is increasingly integrated with Industry 4.0, fostering digital transformation that improves efficiency and competitiveness (Chowdhury et al., 2025). These technologies enable autonomous SCs capable of predictive analytics for improved decision-making, where IoT supports real-time monitoring and cost reduction in SC management (Kusiak, 2023).

These theoretical views highlight the strategic role of Industry 4.0 in SC management. Thus, the resource-based view emphasizes disruption mitigation and profitability (Javed et al., 2024), while dynamic capability theory emphasizes flexibility in adopting new technologies. Moreover, digital SCs encourage circular economy practices, supporting UN sustainable development goals, whereas business-to-business and industrial chain theories provide frameworks for resilience strategies in disruptive scenarios (Sutar et al., 2024).

Circular economy

Circular economy (CE) is essential for sustainable SC management (SSCM), promoting reuse, recycling, and remanufacturing to facilitate smarter use and manufacture of products (Liu et al., 2023). Circular SCs follow a five-stage life cycle: design, production, delivery, operation, and end-of-life (Acerbi et al., 2022). Faramarzi-Oghani et al. (2022) highlight key sustainability indicators and performance optimization methods. However, emerging technologies and resource scarcity, intensified by the COVID-19 pandemic, present both challenges and opportunities for SSCM (Sarkis, 2022).

Some benefits of CE include economic growth, supported by EU strategies benefiting society, industry, and the environment (Onyeaka et al., 2023), as well as business and employment opportunities, particularly in industries like plastics (Kahlert et al., 2022), while reducing resource exploitation and pollution, promoting sustainable growth (Ahmed et al., 2022).

Moreover, Industry 4.0 technologies–AI and big data analytics–boost efficiency and risk mitigation in SC operations (Rashid et al., 2025). Digitalizing SCs also reinforces CE practices, aligning with the UN Sustainable Development Goals (Sutar et al., 2024), where AI facilitates data collection for sustainability, mostly in manufacturing.

3 Methodology

Summative Content Analysis (SCA) was applied to eight open-access Web of Science-indexed articles (December 2024 - March 2025) identified using "Artificial Intelligence," "Supply Chain," and "Circular Economy," arranged from newest to oldest. SCA systematically merges quantitative content analysis with interpretive qualitative insights, providing a robust framework for examining textual data.
The papers included are:

1. Industry 4.0 Technologies (Procedia Computer Science) (Kopeinig et al., 2024).
2. Digital learning, big data analytics, and mechanisms for stabilizing and improving supply chain performance (Barhmi et al., 2024).
3. The role of advanced technologies and supply chain collaboration: during COVID-19 on sustainable supply chain performance (Javed et al., 2025).
4. Smart product platforming powered by AI and generative AI: Personalization for the circular economy (Akhtar et al., 2024).
5. Utilizing intelligent technologies in construction and demolition waste management: From a systematic review to an implementation framework (Wu et al., 2024).
6. Accelerate demand forecasting by hybridizing CatBoost with the dingo optimization algorithm to support the supply chain conceptual framework precisely (Abed, 2024).
7. The future of green skills for the manufacturing sector (Lagorio et al., 2024).
8. Integrating Industry 4.0 for enhanced sustainability: Pathways and prospects (Khan et al., 2025).

SCA starts by tallying specific words or content to identify patterns (Hsieh & Shannon, 2005) and then goes beyond mere frequencies to explore deeper contextual or latent meanings (Krippendorff, 2013). Researchers first select and quantify relevant terms, generating a basic overview; they then investigate how and why these terms are used to reveal interpretive layers not evident from counts alone (Hsieh & Shannon, 2005). By examining both manifest and latent content, SCA uncovers broader cultural, social, or psychological influences on language choices (Elo & Kyngäs, 2008).

4 Results

All eight articles spotlight Industry 4.0 and AI/machine learning, emphasizing data-driven decision-making, advanced manufacturing, and predictive analytics for SC optimization. Big data analytics appear in seven, while #7 referenced "data analysis skills" more indirectly; IoT likewise features in seven (#4 centered on generative AI). Five pieces (#1, #2, #3, #7, #8) discuss digital SCs, linking transformation to operational or sustainability benefits. Six (#1, #3, #4, #5, #7, #8) highlight CE concepts (resource recovery, waste reduction, end-of-life strategies), three address predictive maintenance (#1, #2, #8), and another three end-of-life management (#4, #5, #8). Organizational frameworks and barriers, including policy, training, and readiness, are explored in six (#1, #3, #5, #7, #8, and #2 to some extent).

Digital SC and CE often overlap—particularly in #1, #3, #5, and #8—where real-time data supports resource efficiency and closed-loop operations. AI/Industry 4.0 is near-universal, ranging from algorithmic breakthroughs (#2, #6) to connectivity-driven frameworks (#1, #8). Predictive maintenance (#1, #2, #8) is consistently linked to reduced downtime and waste, while end-of-life management (#4, #5, #8) involves digitally tracking products to facilitate reuse and recycling. All studies note efficiency gains (e.g., lower inventory, energy savings) and environmental benefits, with policy, governance, and skills (in #1, #2, #3, #5, #7, #8) as critical enablers, stressing cross-sector collaboration and regulatory alignment for full digital-circular implementation.

5 Discussion

AI-driven SC analytics can significantly advance CE practices by integrating AI, IoT, and big data analytics for real-time resource tracking, predictive maintenance, and optimized end-of-life product management (Liu et al., 2023; Onyeaka et al., 2023). Predictive analytics and automated resource allocation further boost decision-making in SCs, helping firms anticipate disruptions, minimize surplus inventory, and align with CE principles (Hasan et al., 2023). AI-driven transparency also strengthens sustainability compliance and stakeholder confidence (Dagou & Gurgun, 2024).

However, challenges persist. Many organizations, especially SMEs, lack the expertise and resources to incorporate AI into current SC systems (Chowdhury et al., 2025), and data security and ethical concerns remain pressing (Dagou & Gurgun, 2024). Policy support is vital for guiding environmentally and socially responsible AI integration (Rashid et al., 2025). Collaboration among industry, policymakers, and tech providers is needed to overcome these obstacles and accelerate AI-based CE models.

6 Conclusions

The eight studies highlight key barriers—limited public awareness, technological support, and policy frameworks—and confirm the importance of AI, digital SCs, predictive maintenance, and end-of-life management. All eight report that AI and Industry 4.0 enhance sustainability, six explicitly promote CE strategies, three examine predictive maintenance, and three focus on end-of-life recovery. This supports the hypothesis that AI-driven, real-time trackin,g and proactive maintenance reduce waste and environmental impact, provided organizations align these tools with supportive policies and skill-development measures.

The study's originality lies in its empirical focus on AI's contribution to circular SCs, thus adding to sustainable SC literature. However, reliance on secondary data and potential bias in content analysis are noted limitations. Future research should include empirical case studies and longitudinal approaches to better assess AI's long-term effects on circular SCs.

Finally, AI-driven analytics offers a promising route to achieving sustainability goals. By addressing existing obstacles and fostering cross-sector collaboration, businesses can leverage AI to create resource-efficient, resilient, and circular SC ecosystems.

Overall, this study set out to determine whether – and in what ways – AI-enabled supply-chain analytics support circular-economy objectives through real-time transparency and predictive maintenance. By synthesising insights from eight recent empirical studies, it contributes a focused understanding of how data-centric decision-making, powered by Industry 4.0 technologies, can shrink material footprints and extend product life-cycles. Future research should validate these mechanisms in longitudinal, multi-tier case studies across diverse industries; quantify the social-economic trade-offs of large-scale AI adoption; and explore governance models that protect data privacy while encouraging cross-industry collaboration.

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