Annals of Operations Research (2025) 355:1293–1311
https://doi.org/10.1007/s10479-025-06929-6

PREFACE

Sustainable supply chain innovation pathways in the context of digitalization and the circular economy: an operations research approach

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Published online: 17 November 2025

Abstract
In the context of global climate change and resource constraints, the sustainability of supply chain management has attracted widespread attention across various sectors. This special issue highlights the cutting-edge applications of operations research methods in sustainable supply chain management, particularly within the contexts of digitalization, low-carbon initiatives, and the circular economy. It showcases advances in supply chain resilience modeling enabled by blockchain and machine learning, low-carbon closed-loop game theory, green investment and subsidy strategies, AI-driven low-carbon transformation of small and medium-sized enterprises, and risk mitigation and performance evaluation of circular supply chains. These studies not only extend the theoretical boundaries of supply chain management amid digitalization and the circular economy but also provide practitioners with actionable decision-making tools. Future research should emphasize the integration of interdisciplinary approaches, multi-agent collaborative modeling, and the combination of AI with system dynamics to foster balanced and sustainable development of supply chains across environmental, economic, and social dimensions. Consequently, this special issue establishes a solid foundation for operations research addressing climate change and efficient resource utilization in supply chains.

Keywords Supply chain management · Sustainable operation · Digitalization · Circular economy · Green transformation

1 Introduction

In the era of Industry 4.0, a sustainable and circular supply chain is a modern enterprise sustainable development model that comprehensively considers environmental impacts and resource use efficiency throughout the supply chain (Khan et al., 2021). Specifically, a sustainable and circular supply chain is based on green manufacturing theory and supply chain management theory. It involves a functional network chain structure composed of various

Extended author information available on the last page of the article enterprises that provide products or services to end users, including design, procurement, manufacturing, logistics, sales, recycling, and other links (Song et al., 2019; Khan et al., 2021); its main characteristics are illustrated in Fig. 1. Existing literature has discussed topics related to sustainable and circular supply chain, such as supply chain structure adjustment, green supply chain management, supply chain, and circular economy, etc. (Niu et al., 2019; Ciulli et al., 2020; Khan et al., 2021; Mangla et al., 2021a). It is generally believed that the sustainable and circular supply chain has greater potential and opportunities for enterprises to reduce carbon emissions and enhance their market competitiveness. However, in practice, there are great uncertainties and challenges in developing sustainable circular supply chains.

The realization of carbon neutrality has strong time and quality requirements. The series of measures associated with carbon neutrality will inevitably have a comprehensive and fundamental impact on the original stock supply chain system. Therefore, under the pressure of carbon neutrality, the transformation from the traditional supply chain to the sustainable and circular supply chain will inevitably generate a series of new challenges (Xia et al., 2023; Zhao et al., 2022). Moreover, it is worth noting that the application of digital technologies is intertwined with the achievement of carbon neutrality. Nowadays, digital technologies, represented by blockchain, cloud computing, big data, machine learning, IoT,

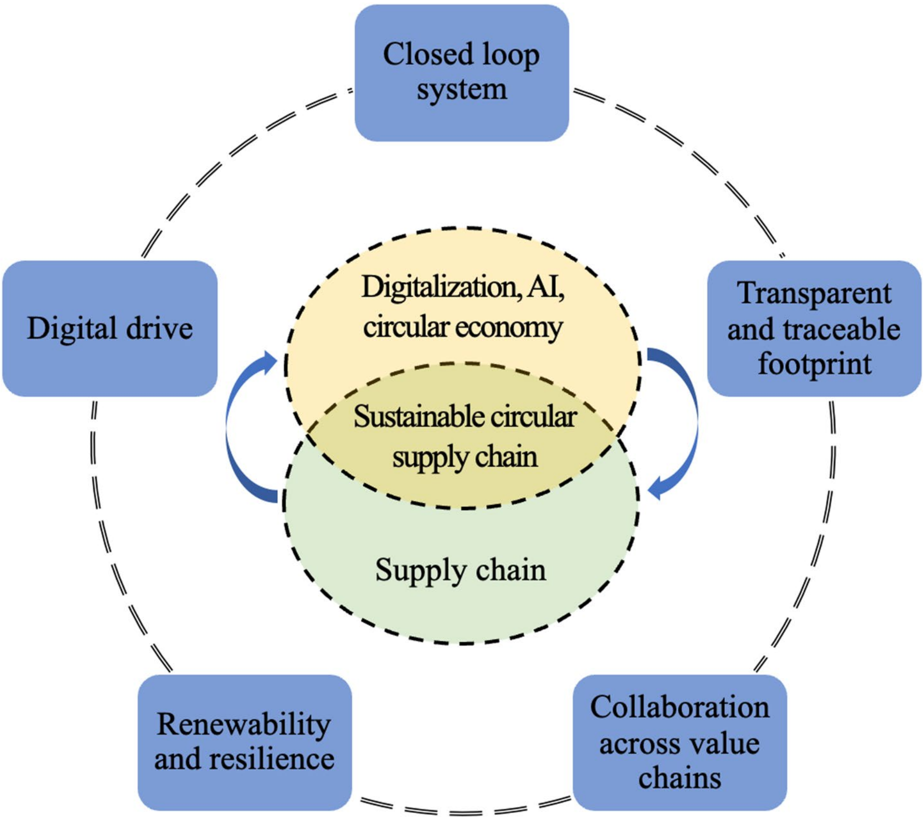

Fig. 1 Characteristics of a sustainable circular supply chain

AI, etc., are gradually applied to the supply chain. Currently, digitalization has become a new feature of supply chain economy, which has a significant impact on the shaping of sustainable and circular supply chain (Holmström et al., 2019; Mangla et al., 2021b). The application of digital technologies could build a more direct and efficient network in the supply chain. It breaks the plane connection between suppliers, manufacturers, retailers, and users in the traditional supply chain in the past, and then establish a three-dimensional, folded, interactive complex network. For example, when core enterprises and upstream or downstream enterprises engage in economic behaviors, digital technologies can automatically identify what methods could be used in each transaction link through setting specific parameters. Digitalization could help to reduce costs and improve resource use efficiency. In high-carbon industries, enterprises use big data, artificial intelligence, and other technologies to form intelligent processing and applications, and digitize entities, and ultimately achieve the purpose of intelligent production and reduce carbon emissions (Ivanov et al., 2019; Li et al., 2024).

In light of these developments, this special issue seeks to present cutting-edge research addressing resource efficiency and climate change challenges in digital, sustainable, and circular supply chains through applications of operations research (OR). To this end, we invited original empirical studies and case reports covering the following topics: sustainable and circular supply chains under background of carbon neutrality, digital sustainable and circular supply chains in improving resource use efficiency, the opportunities and challenges of carbon neutrality for building digital sustainable and circular supply chains, the adoption of digitalization in the logistics and sustainable supply chain, the opportunities and challenges of digitalization for building digital sustainable and circular supply chains, the role of Corporate Social Responsibility in digital sustainable and circular supply chains, and the values of digital technologies in digital sustainable and circular supply chains with OR applications. Despite the challenge of selecting from a large pool of excellent submissions, a rigorous peer review process ensured a fair and thorough evaluation. We intend for this special issue to act as a catalyst, fostering renewed energy and collaboration to further advance this research domain.

The subsequent sections of this preface are structured as follows: We provide a comprehensive review of the literature on sustainable supply chains in Sect. 2. In Sect. 3, the studies included in this special issue are categorized according to their research themes, and a brief overview of the research features of each paper is presented. The last section concludes and offers prospects for future research.

2 Some studies in the literature

In the current global context, sustainable supply chains play a pivotal role in addressing pressing issues such as climate change, resource depletion, and rigorous mandates for carbon neutrality. Conventional linear supply chains, predicated on extractive models, prove insufficient, necessitating integrated approaches that encompass environmental, social, and economic aspects from sourcing to disposal (Linton et al., 2007). Wu and Pagell (2011) elucidated decision-making in sustainable supply chains, highlighting trade-offs and priorities that align economic viability with sustainability, thereby averting risks such as disruptions and regulatory non-compliance. Bibliometric syntheses document a marked increase in sustainable supply chain scholarship post-2010, emphasizing structural reconfigurations and closed-loop mechanisms to support sustainable development objectives (Govindan et al., 2015). Nonetheless, transitional hurdles abound, encompassing implementation ambiguities and systemic overhauls amid urgent carbon timelines (Xia et al., 2023). Consequently, the present context elevates sustainable supply chains as essential strategies, catalyzing innovation trajectories that harmonize economic resilience with ecological limits.

Digitalization acts as a catalyst in sustainable supply chains, harnessing technologies to augment operational efficacy, visibility, and ecological accountability. The provided text delineates how digital instruments dismantle traditional supply chain structures, engendering dynamic networks that streamline exchanges, curtail expenses, and elevate resource utilization, especially in carbon-intensive domains pursuing smart production and emissions abatement (Holmström et al., 2019; Ivanov et al., 2019; Mangla et al., 2021b). Pioneering operations management inquiries, such as Rai et al. (2006), substantiated that digital integration fortifies performance via enhanced information dissemination and cooperative frameworks. Contemporary paradigms in leading journals advocate incorporating Industry 4.0 advancements into sustainable supply chains, facilitating prognostic analytics and instantaneous oversight to curtail waste and amplify adaptability (Olsen & Tomlin, 2020). For example, investigations amid disruptions like COVID-19 underscore digitalization's contribution to sustainable supply chains, with syntheses indicating affirmative influences on performance through automation and low-carbon advancements (Kumar et al., 2024). However, impediments like interoperability and digital waste persist, mandating multifaceted stakeholder involvement (Ben-Daya et al., 2019). In essence, digitalization recasts sustainable supply chains into analytics-propelled ecosystems, forging routes to superior operations and diminished environmental burdens.

The integration of circular economy principles into sustainable supply chains promotes resource efficiency by emphasizing reduce, reuse, remanufacture, and recycle strategies, aiming to minimize waste and extend product lifecycles. Early modeling work in operations management, such as Savaskan et al. (2004), developed game-theoretic models for closed-loop supply chains, demonstrating that decentralized structures with retailer-led collection can optimize remanufacturing incentives and balance economic and environmental outcomes. Subsequent empirical studies have validated these concepts; for instance, Vachon and Klassen (2006) conducted a survey of 84 process industry firms, finding that collaborative re-use practices with suppliers and customers enhance environmental performance, though challenges arise from material complexity and regulatory compliance. More recent research has incorporated digital technologies to support circular flows. Babich and Hilary (2020) explored blockchain's role in enabling traceability in closed-loop systems, showing through conceptual analysis how it reduces information asymmetry and facilitates value recovery in remanufacturing. Empirical evidence from Calzolari et al. (2021) analyzed sustainability reports from 50 European multinational enterprises, revealing that higher supply chain integration correlates with greater adoption of circular practices like recycling and resource efficiency, driven by institutional pressures such as regulations and peer imitation. Overall, these studies illustrate how circular economy principles transform sustainable supply chains into resilient, value-creating systems aligned with broader sustainability objectives.

Above all, in the existing body of operations management research, sustainable supply chains are closely linked to digitalization and circular economy concepts, focusing on essential elements like efficient resource utilization, technology adoption, and closed-loop processes. These core areas of study stand out prominently, yet we contend that further insights are essential across these domains and beyond, especially given ongoing worldwide demands such as achieving net-zero emissions and managing volatile supply networks. While our review encompasses diverse viewpoints and depths of analysis required for these intricate topics, it also highlights differences in methods used to examine conceptual, data-based, and real-world challenges. One primary aim of this special issue is to deepen and broaden the exploration of innovative routes for sustainable supply chains amid digital advancements and circular models, spanning multiple scales (for instance, tactical, functional, and regulatory examinations). Such advancements are apparent in the contributions to this special issue. To engage those keen on the content here, we proceed to outline the key takeaways from these in-depth investigations. For enhanced transparency and side-by-side evaluations, we condense and assess these works based on their subject matter groupings. Whenever feasible, we also draw informal connections among the special issue articles in terms of digital enablement, recycling mechanisms, eco-friendly tactics, and societal viability traits.

3 Studies featured in this special issue

Amid global climate change, resource scarcity, and escalating supply chain risks, developing novel models for sustainable supply chains has become a central research focus. These investigations extend beyond green and low-carbon transformations to encompass dimensions such as digital empowerment, circular economy, policy and institutional innovation, and social sustainability. Research in this special issue particularly addresses the following areas: supply chain transformation driven by digital and intelligent technologies; circular supply chain and closed-loop management; green and low-carbon supply chain strategies and game-theoretic decision-making; and social sustainability in supply chain management optimization.

3.1 Supply chain transformation driven by digital and intelligent technology

Driven by digital and intelligent technologies, supply chains are progressively evolving toward resilience, greenness, and intelligence. Amid the COVID-19 pandemic, a supply chain optimization model integrating machine learning and blockchain technology ensures traceability and resilience of medical supplies (Yadav & Singh, 2024). This integration of blockchain and data-driven approaches not only enhances transparency in procurement decisions but also bolsters the resilience of supply networks. In the context of the digital economy's platform service supply chain, Peng et al. (2023) developed a network equilibrium model involving service providers, platform operators, and demand markets, revealing that the first two actors can promote service quality improvement and collaborative innovation through digital technology. However, challenges such as high investment costs and free-riding behaviors underscore governance issues during digital transformation.

The widespread adoption of digital platforms has also significantly impacted the catering and logistics industries. Regarding the sustainability of third-party takeaway supply chains, Chan et al. (2023) emphasized that platform enterprises must balance economic benefits, social responsibility, and environmental protection, leveraging digital technology to foster sustainable development in the delivery segment. Wang et al. (2024a) further examined a novel dual-system design for C2B crowdsourcing logistics platforms, demonstrating its effectiveness in reconciling environmental preferences of heterogeneous merchants while balancing emission reduction with profitability. Meanwhile, Fan et al. (2024) employed a two-stage evolutionary game model to illustrate how digitalization accelerates collaboration between upstream and downstream enterprises, thereby promoting the green transformation of supply chains.

With the emergence of large language models, Zhou et al. (2025) proposed a ChatGPT application framework for green supply chain management. Their empirical findings suggest that ChatGPT can assist enterprises in conducting green supply chain assessments and enhance the efficiency of green management. Concurrently, Roux et al. (2023) demonstrated that artificial intelligence can improve supply chain productivity and resilience while strengthening low-carbon management capabilities. It is noteworthy that supply chain transformation requires not only real-time operational optimization but also proactive forecasting. To this end, Bouteska et al. (2023) utilized a Wasserstein time series Generative Adversarial Network (WTGAN) to provide forward-looking digital tools for supply chain environmental risk assessment and strategic resilience.

Below, a summary of the special issue articles discussed in this section is provided in Table 1.

3.2 Circular supply chain and closed-loop management

In recent years, circular supply chains and closed-loop management have garnered extensive attention as strategies to address environmental pressures and support industrial transformation. Studies across various contexts reveal diverse development paths and challenges. Under conditions of resource constraints and uncertainty, research on the Indonesian textile industry (Bui et al., 2023) and the Indian textile industry (Mishra et al., 2023a) both underscore the necessity of resource recycling. The former highlights the pivotal role of management strategy, digital infrastructure, and high-level support in resource optimization, employing the fuzzy Delphi method and fuzzy decision experiment. The latter utilizes SAP-LAP and the Explanatory Ranking Process to construct a framework for assessing risks associated with circular supply chain adoption and proposes mitigation measures, thereby offering enterprises actionable transformation strategies. Similarly, Tseng et al. (2023), in their study of Indonesian SMEs, identified waste management practices and circular product design as key factors for performance improvement, while eco-design and green technology provide feasible pathways for SMEs to advance circular models.

At the product life cycle level, consumers' feedback and behavior constitute critical components in the closed-loop management of circular supply chains. Ghosh et al. (2023) found in their study on refurbished laptop consumption that brand, design, price, and practicality are core attributes affecting consumer decision-making, offering empirical support for reverse logistics enterprises to optimize their value propositions. In research on circular supply chains in the retail industry, Hashemi Petrudi and Sharifpour Arabi (2025) identified insufficient consumer motivation, lack of awareness, and inadequate infrastructure as principal barriers to closed-loop operations, providing a foundation for practical enhancements. Additionally, Wamba et al. (2023) conducted a longitudinal case study on plastic waste

Table 1 Details of the featured studies in supply chain transformation driven by digital and intelligent technology

Authors and paper title	Method	Key insights
Yadav and Singh (2024). Machine learning-based mathematical model for drugs and equipment resilient supply chain using blockchain	Analytical modeling	1. Addresses disruptions in medical supply chains like lack of traceability and transparency 2. Blockchain enhances resilience by tackling fraud, poor quality, and data issues 3. Optimizes digital procurement costs using ML-based model with real-time authenticity 4. Formulates MINLP model optimized via LINGO 19.0 for reduced disruptions
Peng et al. (2023). Equilibrium in platform service supply chain network with quality and innovation considering digital economy	Analytical modeling	1. High service quality costs challenge SPs and POs, hindering low-cost access for DMs 2. High innovation capability enables value creation and cost savings with spillover effects 3. Early digital improvements for SPs may not yield revenue growth, risking POs' free riding
Chan et al. (2023). Sustainable successes in third-party food delivery operations in the digital platform era	Qualitative empirical	1. Identifies research gaps in restaurant preferences and multi-dimensional sustainability 2. Platforms must balance economic, social, and environmental responsibilities 3. Future research on digital tech, risks, TBL, and post-pandemic scenarios needed
Wang et al. (2024a). Flexible supply-demand matching mechanism for C2B crowdsourcing logistics platforms with heterogeneous environment-inclined merchants	Analytical modeling	1. Dual-system design accommodates diverse environmental preferences 2. Optimizes driver allocation via queuing analysis for max profitability 3. Market vs. individual awareness oppositely affects allocation 4. Achieves 13.3% emission reduction and 17.7% profit increase 5. Propaganda alone may not reduce emissions without premium controls
Fan et al. (2024). Digitalization drives green transformation of supply chains: a two-stage evolutionary game analysis	Analytical modeling	1. Digitalization promotes green transformation by enhancing innovation, reducing costs, and strengthening management 2. Green behaviors from government and consumers are key drivers to encourage enterprises' transformation 3. Upstream and downstream enterprises can form a cooperative steady state, enabling a rapid green shift
Zhou et al. (2025). Exploration of applications with ChatGPT for green supply chain management	Quantitative empirical modeling	1. ChatGPT aids green assessments and management suggestions 2. Validates effectiveness with 215 company data 3. Encourages large language model adoption for green chains 4. Explores potential research topics in GSCM
Roux et al. (2023). Small and medium-sized enterprises as technology innovation intermediaries in sustainable business ecosystem: interplay between AI adoption, low carbon management and resilience	Qualitative empirical	1. Investigates the role of intangible organizational capabilities in driving AI adoption within SMEs 2. Uses the Perceived Organizational Support theory and survey data from 375 managers to build and test a mode. 3. Finds that AI adoption, facilitated by organizational capacity, leads to improved supply chain productivity, resilience, and low-carbon management
Bouteska et al. (2023). Data-driven decadal climate forecasting using Wasserstein time-series generative adversarial networks	Data analytics	1. WTGAN generates realistic time-series, reduces mode collapse 2. Outperforms other GANs in capturing climate dynamics 3. Reduces computational time significantly 4. Limitations: no historical validation; future: multivariate/extremes

management in Cameroon, revealing significant potential for business and society in plastic recycling, but the urgent need to break through institutional and operational bottlenecks.

From a technical perspective, closed-loop management in circular supply chains relies heavily on innovative tools and methods. For instance, Shang et al. (2024) proposed a hybrid remanufacturing strategy that significantly reduces disposal costs via modular reconfiguration across SKUs, thereby creating a cost advantage for recycling electronic products. Expanding this to policy and market mechanisms, Gong et al. (2025) found through analyses of carbon tax policy and recyclers' risk aversion that rational carbon tax pricing can serve as a vital tool to adjust repurchase prices and stimulate profit balance; however, recyclers' risk-averse behavior substantially influences recycling rates, demand, and profitability. This market-policy-behavior interaction is also evident in research on RFID blockchain frameworks within the steel industry (Rakshit et al., 2025), where decentralized blockchain and IoT technologies enhance transparency, promote cross-enterprise collaboration, and facilitate implementation of circular steel supply chains.

Below, a summary of the special issue articles discussed in this section is provided in Table 2.

3.3 Green and low-carbon supply chain strategy and game decision-making

Currently, achieving carbon neutrality and advancing circular economy transformation has become a global consensus, with the optimization of green and low-carbon supply chains gradually emerging as a central focus of academic research. This special issue primarily concentrates on game-theoretic decision analysis, government policy impacts, recycling and reuse models, green investment strategies, and supply chain optimization.

First, regarding closed-loop supply chains and recycling, Zhang and Yu (2024) demonstrated through differential game analysis that leader altruism and government compound subsidies decisively influence recycling mode selection and power structure formation, unveiling the interaction mechanism between policy incentives and corporate strategies. In the context of electric vehicle used battery secondary utilization, Liu et al. (2023) showed that diversified recycling strategies enhance overall supply chain performance, with cost and subsidies playing a pivotal role in coordination mechanisms. Similarly, Pan and Guo (2023) developed a dual-objective closed-loop supply chain model for the iron and steel industry that considers both economic costs and carbon emissions while incorporating a quantity discount effect. Their study provides theoretical support for the government in making subsidy and quota policies to achieve emission reduction targets. Moreover, Nguyen et al. (2025), using the European Union as a case study, evaluated recycling capacity policies via a system dynamics model, finding that a policy combination integrating innovation and market orientation achieves superior long-term sustainability.

Second, government subsidies and policy games permeate various scenarios in green supply chains. Yi and Wen's (2023) game-theoretic analysis of transnational green supply chains revealed the offsetting effects between importing countries' tariffs and exporting countries' government subsidies, highlighting the critical need for cross-border policy coordination. Xu et al. (2023a) demonstrated that government subsidies maximize the promotion of green and energy-saving products while effectively mitigating market failures. In the electric power sector, Xie et al. (2024) compared carbon emission quota allocation schemes through differential game models, concluding that benchmark quota mechanisms

Table 2 Details of the featured studies in circular supply chain and closed-loop management

Authors and paper title	Method	Key insights
Bui et al. (2023). Causality of total resource management in circular supply chain implementation under uncertainty: a context of textile industry in Indonesia	Qualitative empirical	1. Framework with 20 criteria/7 aspects (managerial, environmental, digital) 2. Key practical criteria: top support, eco-design, rules, tech adoption, funds 3. Enhances resource use and circular performance in textiles
Mishra et al. (2023a). Building risk mitigation strategies for circularity adoption in Indian textile supply chains.	Qualitative empirical	1. Proposes SAP-LAP & Interpretive Ranking Process to analyze and rank risks in India's circular textile supply chains 2. Uses Bayesian Networks to model risk causal relationships and mitigation actions 3. Aids firms in visualizing dependencies and prioritizing risk mitigation strategies
Tseng et al. (2023). Causality of circular supply chain management in small and medium-sized enterprises using qualitative information: a waste management practices approach in Indonesia	Qualitative empirical	1. Waste management/circular design as causal; cleaner production/disclosure/tech as effects 2. Key criteria: eco-design, sustainable design, green tech, waste treatment 3. Hierarchical structure aids SME performance via qualitative data
Ghosh et al. (2023). Analysing product attributes of refurbished laptops based on customer reviews and ratings: machine learning approach to circular consumption	Data analytics	1. Analyzes 1986 laptop reviews to identify key attributes (brand, design, price, utility) influencing refurbished purchases 2. Employs ML (SHAP) and regression to validate sentiment-impact correlations 3. Guides sellers on value proposition and market entry strategies
Hashemi Petrudi and Sharifpour Arabi (2025). Barriers to product return in a circular supply chain: a case from a retailing industry	Data analytics	1. 13 barriers refined to 9 via Grey Delph. 2. Novel GG-BWM ranks lack of motivation, awareness, and infrastructure as top barriers 3. Enhanced GG-BWM improves group decisions
Wamba et al. (2023). Assessing the potential of plastic waste management in the circular economy: a longitudinal case study in an emerging economy	Qualitative empirical	1. Assesses plastic waste value creation in Cameroon's circular economy via 12-organizational study 2. Finds current efforts embryonic, identifies key transition challenges 3. Proposes future research directions
Shang et al. (2024). Hybrid combinatorial remanufacturing for PCB-based products in reversed supply chain	Analytical modeling	1. HCR minimizes costs via module combos 2. Ideal for high material/low op cost products 3. 10–30% savings; regression predicts yield 4. Aids sustainability/carbon neutrality
Gong et al. (2025). Closed-loop supply chain decisions considering carbon tax policy under the recycler's risk aversion	Analytical modeling	1. Tax aligns with costs for optimal rates/demand/utility 2. Risk aversion raises prices, lowers demand/recovery/profits 3. Ignoring aversion increases rates/demand/utility; addressing boosts profits
Rakshit et al. (2025). Advancing circular supply chain management in the steel industry: an RFID-enabled blockchain framework for sustainability	Qualitative empirical	1. RFID-blockchain enhances real-time sharing/performance 2. Management must value tech for faster CSSCM decisions 3. Implications for theory/practice/social in circular economy

significantly improve emission reduction outcomes and long-term profitability. Similarly, Sun et al. (2023) investigated emission reduction modes of suppliers, manufacturers, and energy service companies under carbon quota trading, finding that supplier contract models outperform others in unit emission reduction levels. Their study elucidates the complex relationship between abatement responsibility and profit distribution across contract types.

Finally, in supply chain optimization, Lu et al. (2023) analyzed emerging sales models on short video platforms using game theory and identified a double-edged effect of information sharing between platforms and green manufacturers: when green-preference differences are minimal, manufacturers may suffer losses, whereas retailers consistently benefit. Additionally, Xu et al. (2023b) proposed a joint replenishment strategy for multi-tank refined oil products, offering a viable solution for supply chain decision-making under low-carbon constraints from a logistics optimization standpoint.

Below, a summary of the special issue articles discussed in this section is provided in Table 3.

3.4 Social sustainability and supply chain management optimization

In recent years, social sustainability has gained increasing prominence in supply chain management and has gradually emerged as a key dimension for measuring the effectiveness of supply chain governance. Taking the Indian automobile industry as an example, Sharma et al. (2024) demonstrated that measures such as safety assurances and labor rights protection effectively promote both short-term and long-term supply chain performance, underscoring the central role of social responsibility within the "triple bottom line" framework. In the context of logistics and sustainable supply chain management, harnessing the wisdom of crowds through digital platforms has also become a research focus. Drawing on self-determination theory and cognitive participation theory, Behl et al. (2023) investigated the motivating factors influencing workers' engagement in gamified crowdsourcing, offering an optimization pathway for sustainable logistics management from a behavioral psychology perspective. Concurrently, emerging technologies are recognized as critical drivers in achieving social and environmental objectives. Mishra et al. (2023b) proposed a self-assessment framework for adopting Industry 4.0 decarbonization technologies in the steel industry, systematically identifying barriers to technology adoption and providing guidance for enterprises undergoing social digital transformation. Similarly, Du et al. (2023) highlighted the pivotal role of public infrastructure in promoting social sustainability through an evaluation of productivity within China's water supply industry.

Within the sphere of green travel, Zhang et al. (2023) analyzed the complex interplay between traffic behavior patterns and social sustainability using shared electric vehicle data, thereby expanding the research frontier of the social dimension in green travel governance. Focusing on circular economy development, scholars have actively explored more rigorous supplier evaluation mechanisms. For instance, Liao and Wen (2023) introduced two programming models to address the lack of multi-criteria ranking in sustainable and circular supplier performance evaluation, based on the ELECTRE TRI method, and incorporated decision-makers' preference characteristics via cubic spline interpolation to effectively solve supplier ranking problems. Azizi et al. (2023) advanced group decision-making by applying a linear programming method founded on the feature vector principle, enhancing robustness and providing more precise tools for sustainable supplier selection. Addition-

Table 3 Details of the featured studies in green and low-carbon supply chain strategy and game decision-making

Authors and paper title	Method	Key insights
Zhang and Yu (2024). Differential game analysis of recycling mode and power structure in a low-carbon closed-loop supply chain considering altruism and government's compound subsidy	Analytical modeling	1. Studies recycling mode and power structure combinations under altruism and government subsidy 2. Finds no subsidy favors self-recycling; optimal subsidy favors follower-recycling for leader's utility 3. Shows subsidy rates decrease as leader's altruism increases 4. Provides a long-term dynamic perspective for LC-CLSC decision-making
Liu et al. (2023). Optimal strategy for secondary use of spent electric vehicle batteries: sell, lease, or both	Analytical modeling	1. This study explores marketing strategies (selling, leasing, hybrid) for second-life batteries in a recycling supply chain 2. Diversified leasing options outperform single strategies, with new battery cost and spent battery quality as key factors 3. Remanufacturing costs and subsidies help coordinate the chain and enhance efficiency
Pan and Guo (2023). Dual-objective optimization of a green closed-loop supply chain in steel industry considering quantity discount	Analytical modeling	1. Develops a dual-objective (cost/carbon) green closed-loop steel supply chain model incorporating quantity discounts 2. Considers scale effects, reducing costs by ~ 10% with minimal (1%) emission increase 3. Provides decision-making tools for network design and emission regulation policies
Nguyen et al. (2025). Assessing the impact of EU policies on recycling supply chain: a system dynamics perspective on advancing packaging recycling capacity	Data analytics	1. Models three policy types (innovation, subsidy, market-based) to boost EU recycling capacity using system dynamics 2. Finds innovation policies most effective short-/long-term; market-based best for immediate disruption respons. 3. Proposes an optimal resource allocation: 84% to innovation policies and 16% to market-based policies
Yi and Wen (2023). Game model of transnational green supply chain management considering government subsidies	Analytical modeling	1. Tariffs raise prices, lower greenness/welfare 2. Green preference mitigates tariffs 3. Subsidies increase greenness/prices/profits/welfare 4. Subsidies counter tariffs effectively
Xu et al. (2023a). Pricing policies for green energy-saving product adoption and government subsidy	Analytical modeling	1. Studies pricing/launch strategies for green products under strategic consumers and information sharing 2. Finds low cost/strategy enable info-sharing, price commitment/matching with dual rollover boost profits 3. Consumer subsidies maximize promotion and prevent market failure, aiding sustainable goals
Xie et al. (2024). Dynamic decision-making for carbon emission reduction in the electricity supply chain under different allowance allocation schemes	Analytical modeling	1. Benchmarking enhances reduction/profitability 2. Efforts same in decentralized, higher in centralized under benchmarking 3. Provider more profit under benchmarking; generator/chain under conditions
Sun et al. (2023). Reducing supply chain carbon emissions in consideration of energy service companies under the cap-and-trade mechanism	Analytical modeling	1. Supplier mode higher unit abatement 2. Win-win under low cost difference 3. Profits unaffected by sharing in supplier, fluctuate in third-party 4. Internal decisions create high profits under conditions

Table 3 (continued)

Authors and paper title	Method	Key insights
Lu et al. (2023). Consumer environmental preference information sharing with green manufacturer's short video platform-selling	Analytical modeling	1. Double-edged sharing: manufacturers suffer at low differences, retailers benefit 2. Manufacturer establishes channel at low cost 3. Retailer benefits at low competition/high variability
Xu et al. (2023b). Multi-tank joint replenishment problem with overlapping time windows in refined oil distribution	Analytical modeling	1. Prevents stock-outs/reduces costs 2. Increases overlap by 17.92% 3. GOBL-DE superior in solving

ally, the impact of emergencies has gained importance in assessing social sustainability performance. In the context of COVID-19, Munmun et al. (2023) identified limitations in traditional performance evaluation methods when addressing sudden risks, emphasizing the need to update paradigms of social sustainability management.

In transportation and infrastructure sectors, new evaluation methodologies and governance frameworks have received increasing attention. For example, Ganji et al. (2023) proposed PCE-ERPC, a hybrid model combining data envelopment analysis, prospect theory, and evidential reasoning, applying it to airport performance evaluation and yielding more reasonable outcomes by incorporating decision-makers' preferences. In specific supply chain stages, Maheshwari et al. (2024) systematically reviewed management practices for non-transient deteriorating goods (NIDGs), aligned these with the United Nations Sustainable Development Goals (SDGs), and proposed a future supply chain governance framework integrating environmental, social, and governance (ESG) criteria. Keeping pace with rapid digital commerce growth, Wang et al. (2024b) investigated the selection game of sustainable circular supply chains under competitive conditions, finding that digital channels may outperform traditional supply chains under network externalities and high recycling efficiency, thus supporting enterprises' strategic transformation.

Furthermore, to promote the diffusion of sustainable supply chains, Yaftiyan et al. (2025) proposed an interdisciplinary approach combining evolutionary game theory and system dynamics, demonstrating its potential to balance economic, environmental, and social sustainability in highly uncertain contexts such as epidemics. From an internal enterprise perspective, management capability substantially influences supply chain concentration, while human capital and organizational governance play crucial roles in supply chain optimization (Li et al., 2025). Moreover, through analysis of the agricultural supply chain, Mu et al. (2025) showed that excessive overstocking of intermediate products can diminish overall production efficiency, whereas optimizing resource allocation injects new momentum into the sustainable development of agricultural communities.

Below, a summary of the special issue articles discussed in this section is provided in Table 4.

Table 4 Details of the featured studies in social sustainability and supply chain management optimization

Authors and paper title	Method	Key insights
Sharma et al. (2024). Supply chain socially sustainability practices and their impact on supply chain performance: a study from the Indian automobile industry	Quantitative empirical modeling	1. SCSS dimensions (safety, rights, ethics, welfare) benefit performance 2. Safety/rights impact short/long-term 3. Ethics short-term, welfare long-term qualitative 4. Right mix achieves TBL sustainability
Behl et al. (2023). Engaging and motivating crowd-workers in gamified crowdsourcing mobile apps in the context of logistics and sustainable supply chain management	Qualitative empirical	1. Psychological/behavioral factors for engagement 2. Thematic analysis on interviews for motivation
Mishra et al. (2023b). Adoption of industry 4.0 technologies for decarbonisation in the steel industry: self-assessment framework with case illustration	Qualitative empirical	1. Infrastructure/real-time/learning barriers 2. Framework identifies gaps/improvements 3. Aids SDG 13/net zero
Du et al. (2023). Productivity evaluation of urban water supply industry in China: a metafrontier-biennial cost Malmquist productivity index approach	Data analytics	1. U-shaped gap trend 2. Productivity slows regionally 3. Driven by efficiency/progress; hindered by prices
Zhang et al. (2023). Sustainable operations in electric vehicles' sharing: behavioral patterns and carbon emissions with digital technologies	Data analytics	1. Short-distance not low-carbon 2. Long-distance best reduction 3. Concentrated in commercial/residential, peaks noon/weekends/holidays 4. Users continue low-carbon via public transport
Liao and Wen (2023). Capturing attitudinal characteristics of decision makers in multi-criterion sorting problems for performance evaluation of sustainable and circular suppliers	Analytical modeling	1. ELECTRE TRI for sorting 2. Models derive thresholds/cutting leve 3. Algorithm captures attitudinal characteristics 4. Verifies applicability with example
Azizi et al. (2023). Obviating some of the theoretical barriers of analytical hierarchy process by a revised eigenvector method: a case study in sustainable supplier selection	Analytical modeling	1. Proposes novel LP models based on eigenvector method principles for priority derivation in AHP 2. Models accurately handle consistent and inconsistent matrices, preventing rank reversal and supporting group/fuzzy decisions 3. Demonstrates superiority over existing methods in enhancing precision and robustness for group decision-making
Munmun et al. (2023). Investigation of key performance indicators for performance management of the manufacturing industry in the era of the COVID-19 pandemic	Quantitative empirical	1. Identifies limitations of traditional KPIs in dynamic environments like COVID-19 for the leather industry 2. Selects 15 critical KPIs from 48 via Pareto analysis and expert feedback 3. Uses Z-DEMATEL to analyze cause-effect relationships, pinpointing on-time delivery during pandemic as most crucial

Table 4 (continued)

Authors and paper title	Method	Key insights
Ganji et al. (2023). A new evaluation technique based on DEA, prospect theory and ER approach: assessment of airports	Data analytics	1. Proposes PCE-ERPC, a novel hybrid method embedding Prospect Theory and Evidential Reasoning into three stages of CEM to reflect DMs' preferences 2. Addresses preferences in efficiency matrix generation, weight assignment, and aggregation simultaneously—a first in CEM literature 3. Validates with an airport case study, showing it achieves consensus faster than existing methods like aggressive-APC
Maheshwari et al. (2024). UN sustainable development goals and management of non-instantaneous deteriorating items: a literature review and applications framework	Qualitative empirical	1. Reviews sustainable practices for NIDIs and aligns them with specific UN SDG targets 2. Proposes a novel sustainability modeling framework by hand-mapping NIDI practices to SDGs, addressing ESG aspects 3. Aims to aid both academic analysis and practical decision-making for NIDIs under SDG agendas
Wang et al. (2024b). Should we keep the tradition or follow the trend? The optimal live-streaming e-commerce mode selection in a sustainable and circular supply chain under competition	Analytical modeling	1. Mode selection (digital/traditional/hybrid) depends on commission fee and network externality strength 2. Digital/Hybrid strategies often yield higher product return rates than traditional ones 3. Pure digital SCSC is Pareto optimal only when recycling efficiency-to-cost ratio is above a threshold
Yaftiyan et al. (2025). Diffusing sustainable supply chains: a hybrid evolutionary game theory and system dynamics approach	Analytical modeling	1. Hybrid EGT-SD diffuses sustainability 2. Policies prolong ideal status 3. Recommendations: fines/separation/punishments/rewards/subsidies
Li et al. (2025). Centralization or decentralization? The effect of managerial ability on supply chain concentration	Quantitative empirical modeling	1. Ability positively affects concentration 2. Mediated by reduced costs/asymmetry 3. Enhances managerial role understanding
Mu et al. (2025). Sustainable supply chains with socially undesirable and intermediate outputs: evidence from Chinese agricultural cities	Data analytics	1. DEA assesses chains with externalities 2. Potential to reduce CO_2/increase output 3. Overproduction inhibits final output 4. Optimal allocation key for sustainability

4 Conclusion and future prospects

The coordinated advancement of digitalization, green transformation, and the circular economy is fundamentally reshaping the future development trajectory of supply chains. This study aims to provide a forward-looking perspective, positing that the innovation pathway for sustainable supply chains arises not only from the integration of technology and systems but also represents a critical choice for the global industrial ecosystem to achieve high-quality development within the context of digitalization, green transformation, and the circular economy.

Some research findings featured in this special issue emphasize the multidimensional and interdisciplinary nature of supply chain innovation. On one hand, emerging technologies—from artificial intelligence and large language models to blockchain and the Internet of Things—are profoundly transforming the operational logic of traditional supply chains. These technologies not only enhance supply chain resilience and transparency but also offer new tools and strategies for green, low-carbon, and circular development. On the other hand, practices such as circular supply chains and closed-loop management illustrate the multifaceted value of resource reuse, reverse logistics, and policy incentives. Collectively, these findings underscore the dynamic interplay among policy support, corporate strategy, and social engagement, as well as the decisive role played by cross-level and cross-sector synergies in driving supply chain sustainability. Overall, the sustainable transformation of supply chains can be understood as a complex systemic process involving multiple stakeholders, multidimensional interactions, and continuous dynamic evolution.

Looking ahead, the sustainable transformation of supply chains will continue to face numerous challenges across disciplines, sectors, and borders. Enterprises must urgently explore low-cost, highly flexible digital application scenarios to optimize the balance between investment and returns. Furthermore, supply chain management should extend beyond short-term operational efficiency improvements to establish proactive risk prediction and response mechanisms that bolster overall and strategic resilience. The future sustainable supply chain should not only balance environmental and economic objectives but also be regarded as a long-term evolutionary process driven by technological advancement, social responsibility, and institutional innovation.

Funding This study was funded by the National Natural Science Foundation of China (Grant Nos. 72188101, 72221002, 72303001, 72574001) and the Key Humanity and Social Science Research Project of Anhui Educational Committee (Grant No. SK2021A0243).

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