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PREFACE

Operations research applications in climate change and green transformation: technological innovation, institutional power, and sustainable supply chain governance

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Abstract
Climate change and the pressing need for green transformation represent one of the most critical challenges of global economic and environmental systems. In response, this special issue examines how operations research (OR) can drive sustainable supply chain governance through technological innovation and institutional power. Comprising 42 rigorously reviewed articles, this collection explores diverse themes such as low-carbon transformation, circular economy strategies, energy system optimization, digitalization, and socio-institutional mechanisms. These studies introduce innovative OR applications, such as AI and blockchain implementations, game-theoretic frameworks, and policy assessment mechanisms, to navigate intricate sustainability trade-offs and facilitate multi-stakeholder decision-making within green supply chains. By integrating theoretical advances with practical insights, this issue offers valuable contributions for researchers, practitioners, and policymakers aiming to achieve sustainability in supply chain operations. It underscores the imperative of interdisciplinary collaboration and systemic approaches to foster resilient, inclusive, and ecologically responsible supply chains in the era of climate urgency.

Keywords Operations research · Supply chain management · Green transformation · Technological innovation · Institutional power

1 Introduction and background

Optimizing resource use efficiency, stabilizing climate change, and striving to limit the increase in global average temperature to 1.5°C above the pre-industrial levels have become the consensus of human society. As of 2024, more than 150 countries have announced their net-zero carbon emission targets. Moreover, the majority of countries have a specific timeframe for carbon neutrality, such as the United States, the European Union, Canada, Japan, and other countries announced that they would achieve carbon neutrality by 2050, while China issued a series of implementation plans under the goals of carbon peak by 2030 and

Extended author information available on the last page of the article carbon neutrality by 2060 (Zhao et al., 2022). In practice, firms, particularly those in high-emission industries, are the key actors in achieving the carbon neutrality target. Under the greater pressure of carbon mitigation, developing sustainable and circular supply chains has become a powerful way for firms to improve resource use efficiency, alleviate the carbon constraints, and enhance their market competitiveness.

As the Sustainable Development Goals (SDGs) proposed by the United Nations gain worldwide endorsement, it has become inevitable for operations and production management to advance the circular economy and transition from conventional supply chains to sustainable supply chains (Thorlakson et al., 2018; Feng & Zhu, 2024). The green transformation of supply chains requires the joint action of technology and social systems. Process improvements and digital intelligent tools based on green manufacturing offer a practical pathway toward the low-carbon transformation of industrial processes (Mangla et al., 2021). Concurrently, policies and regulations, market mechanisms, and corporate social responsibility collaboratively shape the institutional environment for green transformation, creating both external constraints and internal incentives that influence corporate behavior (Song et al., 2024). It is worth noting that enterprises need to tradeoff opportunities and challenges in developing digital sustainable and circular supply chain. Therefore, it is necessary to apply scientific and effective OR methods to analyze the tradeoffs. OR is a cutting-edge analytical method that analyzes the optimal allocation of resources, determines the optimal solution, and helps scientific decision-making according to the requirements of the target problem. It has been widely used in computing, manufacturing, production scheduling, resource allocation, inventory management, logistics management, transportation, and supply chain management.

Some studies in this special issue aim to provide cutting-edge research on supply chain green transformation pathways and climate change-driven issues through OR applications. Through this call, we solicited original contributions to this emerging field. Intended as a platform for advancing understanding of operational challenges, this special issue leverages technological innovation and institutional power to foster sustainable supply chains. Among the 42 accepted papers, the following themes are discerned: carbon mitigation and green supply chain management, the digitalization and green supply chain management with OR applications, investigate the effects of digitalization on the strategic objectives of green supply chain management, the drivers and barriers for firms' adoption of green supply chain management, and increase efficiency based on flexible automation of physical processes via robotics.

The subsequent structure is arranged as follows. In Section 2, we review the existing literature and clarify the need for this special issue to focus on sustainable supply chain management. Section 3 provides a detailed analysis and discussion of the papers collected for this special issue. Finally, we conclude with a summary.

2 Need for the study on sustainable supply chain management driven by technological innovation and institutional forces

The intensifying climate crisis and concomitant policy responses have transformed supply-chain management from a primarily cost-and-service problem into a multi-dimensional systems engineering challenge. Two classes of risk are now central to operational decision-making. (1) Physical risks: direct, stochastic damage to facilities, transport links and production capacity caused by extreme weather and long-term climatic change. (2) Transition risks: policy, market and technology shifts that alter relative costs and demand patterns. Operations research and supply-chain studies have formalized how such risks propagate across multi-tier networks (the so-called "ripple effect") and how lean, globally optimized designs can become fragile under these shocks (Craighead et al., 2007; Ivanov et al., 2017; Pankratz et al., 2024). These literatures show that traditional single-objective cost minimization is insufficient: network design and operational control must be recast as stochastic, multi-criteria problems that trade off efficiency, robustness and environmental outcomes.

Concurrently, the SDGs and related decarbonization targets require technology-driven transformations of operations. Scholars have examined both the enabling potential and the unintended consequences of technological change that can improve visibility, enable dynamic re-routing, and reduce waste, but they also introduce complexity, integration costs and possible rebound effects (Kache & Seuring, 2017; Tao et al., 2024). From a theoretical standpoint, the dynamic capabilities perspective indicates that firms' ability to seize and reconfigure resources determines whether technological affordances translate into sustained environmental performance rather than ephemeral, local improvements (Teece et al., 1997). In short, technological tools are necessary but not sufficient—operations theory must explain how technology choices interact with network topology, investment timing, and life-cycle emissions accounting.

Moreover, a substantial body of literature stresses that institutional power—regulation, standards, procurement policy, financial disclosure, and normative pressures—are decisive selectors of green supply chain practice (Feng & Zhu, 2024; Shang et al., 2024). Organizational and institutional theories show that coercive, normative and mimetic pressures shape the timing, depth, and form of green transformation, while institutional complexity (conflicting rules across jurisdictions, uneven enforcement) leads to fragmentation and strategic compliance that can blunt policy intent (Sarkis et al., 2011; Li & Lin, 2025). From an operations perspective, institutional levers change incentive structures for upstream investment, inventory policy and reverse-logistics design. Thus, rigorous models of sustainable operations must integrate institutional constraints with technical feasibility and firm incentives rather than treat institutions as exogenous, monolithic forces.

Above all, while classical operations research offers a robust toolkit and conceptual foundations, the multifaceted nature of contemporary environmental and climate challenges necessitates an integrated research approach that incorporates system optimization, socio-technical analysis, and institutional governance. These theoretical and empirical gaps define an urgent and programmatic research agenda for the field of operations management. This agenda underscores the need for a focused, operations-oriented special issue that moves beyond siloed solutions to advance integrative and policy-relevant scholarship.

3 Analysis and discussion

Amid the climate crisis and energy transition, the green transformation of supply chains has become a focal point in global industrial competition. This transition is not merely a technical or policy challenge but a complex systems engineering problem involving technology, economics, society, and institutions. Research featured in this special issue addresses several key areas, including new energy vehicles and low-carbon transformation, circular economy and green supply chain, energy system and environmental governance, sustainable path of digitalization and intelligence, and social and institutional driving mechanism of sustainable innovation, as illustrated in Fig. 1.

3.1 New energy vehicles and low-carbon transformation

New energy vehicles (NEVs) play a crucial role in the global energy transition and low-carbon development; however, evidence from various studies indicates existing differences and challenges regarding their environmental and economic benefits. In the context of China's experience, Li et al. (2023) assessed the emission reduction potential of public transport electrification by considering regional disparities. Their findings reveal that the transportation energy transition can significantly reduce carbon emissions and environmental burdens, but the overall emission reduction effect may be undermined by increased electricity demand and regional variations in power grid structures. Similar challenges are evident in the promotion of passenger vehicles. Su et al. (2023a) examined the relationship between NEV development in China and the distribution of various pollutants using quantile regression analysis. Their results indicate that battery electric vehicles outperform plug-in hybrid electric vehicles in environmental benefits; however, the emission reduction effect remains constrained by technology maturity and market size. Consumer behavior also influences the adoption of NEVs. Sonar et al. (2023) found that charging time, driving range, and price are critical factors affecting consumers' vehicle purchase decisions, while battery performance shapes user experience through technical factors. These findings underscore that technological breakthroughs and cost control are central drivers promoting NEV adoption.

At the industrial chain level, greening the NEV supply chain exhibits characteristics of a strategic game. Adnan et al. (2023) shifted attention to supply chain benefit patterns, finding that manufacturers must balance green technology benefits against high investment costs, with the bargaining power of retail channels further influencing pricing strategies and investment allocation equilibria. Simultaneously, subsidy policies emphasize the importance of the institutional environment. Although government subsidies effectively stimulate the NEV market in the short term, Zhang et al. (2024) suggest that, with gradual policy withdrawal, enterprise-driven technological improvements and market-oriented subsidy

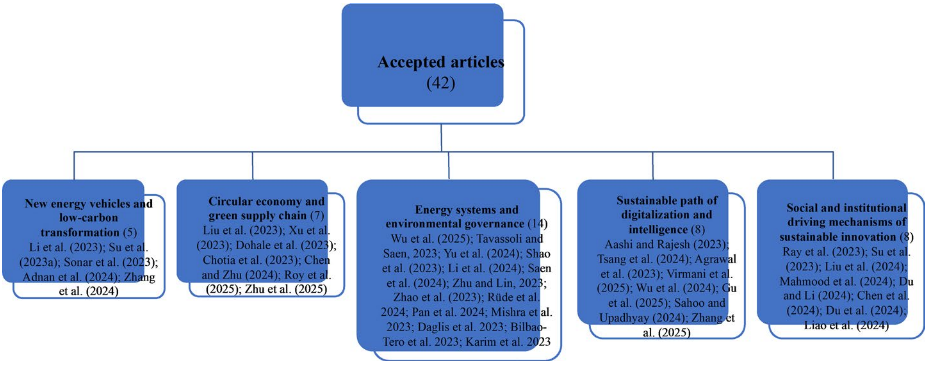

Fig. 1 Classification of studies

mechanisms are expected to become the primary forces supporting sustainable industry development in the medium to long term.

Above all, the discussions in this section regarding the special issue articles are summarized in Table 1.

Table 1 Details of the featured studies in new energy vehicles and low-carbon transformation

Authors and paper title	Method	Key insights
Li et al. (2023). Life cycle assessment of car energy transformation: evidence from China	Data analytics	Proposes three transition models for buses/taxis across China's regions. Full transition could save 45.8 M tons of coal but strain electric grids. Integrates regional power mix with transport policy for robust energy transition.
Su et al. (2023a). Explore the environmental benefits of new energy vehicles: evidence from China	Quantitative empirical modeling	NEVs show limited benefits due to growth/tech limitations. Coexistence leads to variable pollution. BEVs more effective than PHEVs. Indispensable for emissions prevention, effects not fully evident.
Sonar et al. (2023). Examining the causal factors of the electric vehicle adoption: a pathway to tackle climate change in resource-constrained environment	Qualitative empirical	Charging time/range/price top criteria. Battery capacity/transmission/motor as causes. Power/price/torque as effects. Sensitivity confirms robustness.
Adnan et al. (2023). Pricing and green investment strategies for electric vehicle supply chain in a competitive market under different channel leadership	Analytical modeling	Models two competing EV supply chains under three game scenarios to analyze pricing and green investment strategies. Manufacturers balance wholesale price/green level with investment costs; retailers set retail price. Demand depends on price, green awareness, and brand reputation.
Zhang et al. (2024). Can subsidies promote electric vehicles' sustainable development? A general equilibrium perspective on substituting enterprises for government	Analytical modeling	Subsidies stimulate demand/substitution. Enterprise subsidies sustain growth. Positive stakeholder/economic effects. Companies need subsidy efforts/tech cost reduction.

3.2 Circular economy and green supply chain

Currently, manufacturing and traditional high-energy-consuming industries face “double pressures” from environmental governance requirements and demands for intelligent transformation. Within this context, the circular economy and green supply chain have emerged as core strategies for enterprises to enhance competitiveness and achieve sustainable development, attracting considerable attention. From the perspective of internal drivers, the formation mechanism of eco-innovation is particularly critical. Liu et al. (2023) demonstrate that corporate social responsibility engagement and technological innovation efficiency are primary drivers promoting eco-innovation in the manufacturing sector’s transition toward a circular economy, underscoring the proactive role of enterprises in green transformation. Xu et al. (2023) empirically analyzed the impact of China’s green supply chain pilot policy at the city level using a quasi-natural experiment. Their results indicate that institutional design exerts a significant guiding effect on corporate green innovation, providing empirical support for the advancement of circular and green supply chains.

Nevertheless, the green transformation process has encountered challenges. Several studies reveal that various industries face multiple barriers when implementing circular economy and green supply chain practices. For example, in the textile and apparel industry, insufficient policy awareness and the lack of government support and subsidies constitute significant obstacles that constrain enterprises from integrating circular economy principles with smart technologies (Dohale et al., 2023). Extending this to energy-intensive industries, Chotia et al. (2023) applied the Interpretive Structural Modeling (ISM) approach to hierarchically analyze barriers to green supply chain management in the cement industry. They identified key challenges, including low return on investment, missing environmental performance indicators, inadequate government support, and limited social responsibility awareness among senior managers, which collectively hinder the implementation of green supply chain initiatives. Furthermore, Zhu et al. (2025) also discussed the green supply chain management in the agricultural industry. These findings highlight the restrictive influence of industry-specific characteristics on green transformation pathways and emphasize the necessity of governance mechanisms and governmental intervention.

In a more complex multi-agent environment, the dynamics of synergy and conflict within circular supply chains merit significant attention. Chen and Zhu’s (2024) study on the plastic circular supply chain reveals that, although cap-and-trade policies promote emission reductions among fossil fuel enterprises, they may concurrently impede the adoption of renewable plastics by multinational corporations to some extent. This work uncovers the intricate trade-offs between carbon emission reduction policies and recycled plastic utilization, alongside their nonlinear effects on total carbon emissions, offering a theoretical foundation for the collaborative governance of plastic circular supply chains. Concurrently, resource efficiency and coordinated governance within supply chains remain critical to achieving circular economy objectives. Roy et al. (2025) identified key attributes and their interactions in circular supply chain implementation using fuzzy interpretive structural modeling and structural equation modeling, further emphasizing the systemic importance of multi-stakeholder collaboration in the evolution of green supply chains.

Above all, the discussions in this section regarding the special issue articles are summarized in Table 2.

Table 2 Details of the featured studies in circular economy and green supply chain

Authors and paper title	Method	Key insights
Liu et al. (2023). Exploring drivers of eco-innovation in manufacturing firms' circular economy transition: an awareness, motivation, capability perspective	Quantitative empirical modeling	Proposes CSR social engagement and tech innovation efficiency (capability) as key drivers of circular eco-innovation. Environmental regulation and industrial competition moderate these relationships with distinct effects. Empirical study of 181 Chinese manufacturers confirms drivers and contextual influences.
Xu et al. (2023). The green innovation effect of the city's green supply chain pilot: evidence from a quasi-natural experiment	Quantitative empirical modeling	City GSC pilot policies significantly boost corporate green innovation performance. Driven by stricter urban regulation and higher supply chain standards. Effect is stronger in cities with environmental laws and firms with green investors.
Dohale et al. (2023). Evaluating circular economy and smart technology adoption barriers in the Indian textile and apparel industries using neutrosophic ISM	Qualitative empirical	Identifies 11 CE–ST adoption barriers in Indian textile/apparel industries. Applies novel Neutrosophic-ISM to analyze barrier interdependencies. Unawareness of policies and lack of government support are key barriers. Proposes strategies to aid policymakers and industry in CE–ST implementation.
Chotia et al. (2023). Barriers for adoption of green supply chain management in cement industry: an interpretive structural modelling (ISM) approach	Qualitative empirical	Identifies 14 GSCM barriers in Indian cement industry via ISM modeling. Key drivers: lack of metrics, high cost, weak policies, management resistance. Resolving these enables seamless green supply chain integration.
Zhu et al. (2025) Low carbon policy: a green agriculture supply chain perspective	Analytical modeling	Centralized decisions yield higher order quantities and emission cuts than decentralized. Carbon trading only benefits green firms above a specific price threshold. Revenue-sharing contracts enable win-win outcomes under mixed carbon policies.
Chen and Zhu (2024). A three-stage game model of plastic circular supply chain management in the context of cap-and-trade and plastic packaging regulations	Analytical modeling	Cap-and-trade boosts petrochemical emission efforts but may reduce recycled plastic use. Plastic fines raise recycling rates yet discourage carbon reduction. Scope 3 commitment increases recycling but raises petrochemical emissions; total emissions show nonlinear trend.
Roy et al. (2025). Integrated fuzzy total interpretive structural modeling and partial least squares structural equation modeling to understand resource efficient circular supply chains	Qualitative empirical	Identified 16 CSC attributes via fuzzy-TISM and MICMAC analysis. Policy, collaboration, and stakeholder internalization drive R&D, logistics, and skills. Enables material flow optimization, lifecycle sustainability, and supply chain resilience.

3.3 Energy systems and environmental governance

Currently, the global energy system faces dual challenges: achieving low-carbon transformation while ensuring environmental governance. Balancing green development with energy security has become a central focus. From combined cycle power plants to energy supply-supply-demand-storage systems, from carbon emission reduction policies to green financial instruments, recent research shows multi-dimensional exploration and innovation.

In terms of energy production, traditional modes such as coal-fired and combined cycle power plants remain important but require improvements in environmental efficiency. Wu et al. (2025) applied the enhanced hull algorithm to assess environmental efficiency in China's coal-fired power supply chain enterprises, revealing generally low efficiency and underscoring the urgency of transforming traditional energy sources. Likewise, Tavassoli and Saen (2023) studied combined cycle power plants in Iran and emphasized that environmental efficiency critically influences overall sustainability, highlighting the need for optimizing infrastructure and governance mechanisms. From a broader perspective, Yu et al. (2024) developed a collaborative measurement and multi-objective optimization model for integrated energy supply-transport-demand-storage systems, identifying a transition pathway where renewable and nuclear energy gradually replace coal.

At the policy and institutional level, empirical analyses of China's Top 1000 Energy Consumption Program (Shao et al., 2023) and environmental protection tax (Li et al., 2024) demonstrate that production-oriented carbon reduction projects and tax instruments can effectively improve carbon emission performance and reduce energy consumption. However, their effectiveness varies significantly across regions, industries, and ownership types. Similarly, Saen et al. (2024) examined carbon emission quota redistribution under the cap-and-trade system using data envelopment analysis, offering methodological insights for optimizing carbon market policies. Additionally, research on energy poverty by Zhu and Lin (2023) indicates that gains from efficiency improvements may be offset by rebound effects, necessitating demand management strategies to ensure energy equity in policy design.

Technological advancement is also recognized as a key enabler of low-carbon development and environmental governance. Zhao et al. (2023) showed that information and communication technology serves as a critical catalyst for carbon unlocking, with green development efficiency playing a positive moderating role, thus providing a digital pathway toward carbon neutrality. In smart grid contexts, Rüde et al. (2024) demonstrated that load overlaps caused by demand-side interactions require investors to update planning models to accommodate new technologies such as electric vehicles and intelligent demand response within distribution networks. Furthermore, Pan et al. (2024) constructed a multi-objective assessment model based on data envelopment analysis to dynamically monitor environmental risks and support urban environmental governance through big data tools. Mishra et al. (2023) found that adopting renewable energy technologies within supply chain enterprises enhances supply chain resilience, enabling stable operations amid energy interruptions and offering practical guidance for enterprise energy management and green supply chain transformation.

From an international perspective, external risks and cross-country differences in energy systems warrant significant attention. Daglis et al. (2023) found that solar energy events in the United States can exert substantial spillover effects on both the energy system and other economic sectors, underscoring the interconnected risks within energy systems. Bilbao-Terol et al. (2023) highlighted the particular vulnerabilities of Spain and Portugal within the Southern European energy market, providing empirical insights for strengthening the resilience of regional energy supply chains. Karim et al. (2023) investigated the relationship between blockchain digital currencies and sustainable resources, revealing asymmetric spillover effects that reflect complex interdependencies. Their results provide a new reference perspective for the blockchain industry and supply chain managers to promote the collaborative management of green digital finance and resources.

Above all, the discussions in this section regarding the special issue articles are summarized in Table 3.

3.4 Sustainable path of digitalization and intelligence

In the exploration of sustainable supply chains and business models, digital and intelligent technologies are increasingly recognized as core drivers. Enterprises must not only achieve economic performance advantages but also create social and environmental value. Centering on this critical issue, several studies included in this special issue illuminate how digitalization and intelligence enable sustainable development from diverse perspectives, offering multidimensional practical insights.

First, regarding supply chain evaluation and optimization, research reveals a trend toward integration and multi-objective optimization. Aashi and Rajesh (2023) incorporated social sustainability into their decision-making framework using data envelopment analysis, providing methodological support for managers to embed social factors within intelligent supply chain management. Focusing on cold chain e-commerce, Tsang et al. (2024) proposed a joint sustainable optimization model for order packaging and distribution routing, which, through algorithmic support, reduced resource consumption and enhanced customer satisfaction, exemplifying the synergy between digitalization and low-carbon initiatives.

Digitalization also serves as a pivotal "bridge" between carbon reduction and the circular economy. Agrawal et al. (2023) combined intuitionistic fuzzy sets with Analytic Hierarchy Process and Evaluation based on Distance from Average Solution methods to identify circular business model potentials that overcome decarbonization barriers, proposing a circular economy framework where digital supply chains are key enablers. In a broader investigation of digital circular supply chains, Virmani et al. (2025) applied the Z-number fuzzy method to analyze key success factors and performance metrics, revealing that optimization outcomes depend heavily on enhanced strategic vision and circular economy awareness. Performance gains are primarily reflected in automation, process optimization, and inventory forecasting capabilities.

Simultaneously, the enabling role of digital-intelligence technologies in supply chain resilience is becoming increasingly evident. Wu et al. (2024) constructed a theoretical framework illustrating how big data intelligence, the IoT, AI, blockchain, and other technologies improve supply chain visibility, forecasting, and decision-making capabilities. Their study highlights that the core challenge lies in establishing appropriate enabling frameworks and mechanisms. Similarly, while blockchain applications in sustainable supply chains within the construction sector enhance transparency, they also introduce risks across economic, environmental, and social domains. Gu et al. (2025) recommend prioritizing economic and environmental sustainability in promoting blockchain adoption.

Moreover, integrating digitalization and intelligence with management practices demonstrates potential for broader applications. Sahoo and Upadhyay (2024) examined how Industry 4.0, Lean Six Sigma Practices, and Circular Supply Chain Management impact triple bottom line performance (economic, environmental, social) in manufacturing firms. Their findings indicate that digital technologies significantly bolster economic performance, yet maximize environmental and social benefits only when coupled with coordinated management and robust recycling mechanisms. Similarly, Zhang et al. (2025) demonstrated how digital healthcare can foster resource conservation and low-carbon outcomes but noted that

Table 3 Details of the featured studies in energy systems and environmental governance

Authors and paper title	Method	Key insights
Wu et al. (2025). Environmental efficiency evaluation of China's coal-fired electricity supply chain enterprises with large-scale datasets: an enhanced build hull algorithm	Analytical modeling	Proposes enhanced EBH algorithm for faster large-scale DEA computation. Achieves 5× speed vs. benchmark, 100× faster than traditional DEA. Only 6.75% of China's coal-power firms are environmentally efficient. Efficiency distribution shows polarized bimodal pattern.
Tavassoli and Saen (2023). Sustainability measurement of combined cycle power plants: a novel fuzzy network data envelopment analysis model	Analytical modeling	FNDEA assesses fuzzy sustainability. 46% good performance. Environmental impacts overall efficiency.
Yu et al. (2024). Synergy level measurement and optimization models for the supply-transmission-demand-storage system for renewable energy	Data analytics	Proposes measurement and optimization models for renewable energy "supply-transmission-demand-storage" synergy. Post-optimization synergy rises 10.3%, renewables dominate power by 2040. Energy storage grows 15.8% annually; inter-provincial transmission slows to 2.15%.
Shao et al. (2023). Effectiveness of production-oriented carbon reduction projects: evidence from the top 1000 energy-consuming enterprises program	Quantitative empirical modeling	MNMCPI rose 44.7%, showing catch-up, innovation, and slight tech leadership effects. T1000P policy boosted CEP via environmental regulation, but with group heterogeneity. Private/small firms advanced faster; eastern/key cities led tech progress.
Li et al. (2024). Does implementation of a environmental protection tax reduce energy consumption: evidence from China.	Quantitative empirical modeling	Environmental protection tax reduces China's energy consumption significantly. Effects stronger in central/western regions and pollution-controlled zones. Mechanisms: boosts R&D innovation, optimizes industry, strengthens tax enforcement.
Saen et al. (2024). An advanced data analytic approach for reallocating green gas emissions in cap-and-trade context	Analytical modeling	Develops DEA model for cap-and-trade emission redistribution among DMUs. Links desirable/undesirable outputs, maximizes collective efficiency. Computes efficiency intervals to handle multiple optimal solutions. Validates model with case study on practical emission reallocation.
Zhu and Lin (2023). Why is efficiency improvement ineffective in alleviating energy poverty? The nonnegligible rebound effect	Quantitative empirical modeling	Energy efficiency significantly reduces energy poverty via demand channel. Urban impact exceeds rural; rebound effect cuts poverty reduction by 61.4%. Robust findings inform quantitative energy poverty alleviation strategies.
Zhao et al. (2023). Is enhanced information and communication technology efficiency a powerful weapon for carbon unlocking? The case of China.	Quantitative empirical modeling	ICT efficiency reduces carbon lock-in, especially in high-efficiency provinces. Green development enhances ICT's carbon unlocking effect. Mediators: carbon efficiency and technological innovation drive the transition.

Table 3 (continued)

Authors and paper title	Method	Key insights
Rüde et al. (2024). Multi-period electricity distribution network investment planning under demand coincidence in the smart grid	Analytical modeling	Proposes policy for multi-period grid planning with evolving consumption patterns. Analyzes impact of new tech and network topologies on investment costs. Develops optimization model for long-term grid planning under demand variability.
Pan et al. (2024). A multi-objective model for the assessment of potential environmental risk using big data covering air quality	Analytical modeling	Develops DEA model using daily AQI data to assess urban environmental risks. Groups 316 Chinese cities into 4 clusters to eliminate temporal heterogeneity. Risk frequency increased in 2021 due to post-COVID industrial recovery.
Mishra et al. (2023). Renewable energy technology adoption in building a sustainable circular supply chain and managing renewable energy-related risk	Qualitative empirical	Identifies 7 RET adoption constructs for sustainable circular supply chains. UTAUT-based model confirms expert intentions to adopt RET in India. Awareness, resilience practices, and green business models drive RET adoption.
Daglis et al. (2023). Solar events and the US energy sector: a novel sectoral spillover GVAR approach introducing indirect GIRFs (IGIRF).	Data analytics	Links solar events to US energy sector via novel network-theoretic model. Uses global VAR and new indirect impulse response (IGIRF) method. Solar activity indirectly boosts manufacturing, finance; harms agriculture, mining. Construction, retail show no significant response to solar events.
Bilbao-Terol et al. (2023). Evaluating Energy Security using Choquet Integral: analysis in the southern EU countries.	Qualitative empirical	Proposes MCDM method with Choquet Integral for EU energy security risk assessment. Focuses on Spain/Portugal, incorporating expert knowledge and indicator interdependencies.
Karim et al. (2023). Examining the avenues of sustainability in resources and digital blockchains backed currencies: evidence from energy metals and cryptocurrencies	Quantitative empirical modeling	Examines asymmetric spillovers between blockchain currencies and sustainable resources. Finds cluster dominance between crypto and resource-efficient metals via time-varying analysis. Stresses natural resources' key role in achieving sustainable supply chains.

telemedicine requires optimized trade-offs between service speed and cost. Collectively, these studies underscore that digitalization is a fundamental enabler of green and circular supply chains; however, realizing its full potential necessitates complementary management design and risk mitigation strategies to convert digital advances into sustainable development trajectories.

Above all, the discussions in this section regarding the special issue articles are summarized in Table 4.

3.5 Social and institutional driving mechanisms of sustainable innovation

In the context of global sustainable development, social and institutional factors profoundly shape innovation pathways and practical approaches. Using agriculture as an example, government policy instruments exhibit significant variation in promoting smallholder farmers'

Table 4 Details of the featured studies in the sustainable path of digitalization and intelligence

Authors and paper title	Method	Key insights
Aashi and Rajesh (2023). Integrating social sustainability into supplier evaluation using data envelopment analysis	Data analytics	Proposes DEA model for socially sustainable supplier selection. Compares DMUs to identify best supplier using integrated criteria. Validated in fast-food chains; enhances ESG performance.
Tsang et al. (2024). A joint sustainable order-packing vehicle routing optimisation for the cold chain e-fulfilment	Analytical modeling	Proposes JOSOPMDP model for sustainable cold chain e-fulfillment. Optimizes thermal packaging and routing to cut cost and boost satisfaction. Reduces environmental impact while maintaining product quality and delivery efficiency. Achieves 3.26% cost savings and 47.88% higher customer satisfaction.
Agrawal et al. (2023). Unlocking circular business model avenues to achieve net-zero emissions: A model-driven approach grounded on inter-valued intuitionistic fuzzy sets	Qualitative empirical	Identifies key decarbonization barriers in rubber industry supply chains. Proposes circular business models as solutions, emphasizing digitalization.
Virmani et al. (2025). The greenwash era is over, now performance matters: a Z-Number analysis of critical success factors and performance outcomes to achieve resource efficient digital circular supply chain management practices	Qualitative empirical	Identifies CSFs and POs for digital circular supply chains using Z-number fuzzy methods. Top CSF: Strategic DCSCM vision; top PO: Process automation and demand forecasting. Sensitivity analysis confirms robust CSF rankings despite weight variations.
Wu et al. (2024). How does digital intelligence technology enhance supply chain resilience? Sustainable framework and agenda	Qualitative empirical	Proposes digital intelligence tech (AI, IoT, blockchain) for supply chain resilience. Analyzes empowerment mechanisms and challenges in SCRM framework.
Gu et al. (2025). Analyzing sustainability risks associated with blockchain technology implementation in the sustainable supply chain of construction industry: a fuzzy-based MCDM approach	Qualitative empirical	Identifies blockchain sustainability risks in construction SSCM. Economic risks (profit loss, trust) and high energy use are top threats.
Sahoo and Upadhyay (2024). Improving triple bottom line (TBL) performance: analyzing impacts of industry 4.0, lean six sigma and circular supply chain management	Quantitative empirical modeling	Industry 4.0 boosts economic performance directly, but not environmental/social outcomes. LSSP and CSCM fully mediate environmental benefits, CSCM alone mediates social benefits. Survey of 224 firms shows mediation roles; guides strategic sustainability frameworks.
Zhang et al. (2025). Sustainable healthcare supply chains with telemedicine: price and service rate decisions	Analytical modeling	Telemedicine pricing must be lower than physical hospitals to optimize profit/welfare. Fast telemedicine services outperform high-quality ones in profitability. Telemedicine may harm sustainability if technical limits are high or cost differences small.

adoption of zero-budget natural agriculture. Specifically, when environmental damage is severe, direct cost subsidies more effectively encourage sustainable agricultural practices; however, under moderate to low environmental pressure, the optimal policy depends on the proportion of farmers with environmental awareness (Ray et al., 2023). Moreover, sustainable development relies heavily on the cooperation and engagement of diverse social actors.

An empirical study in Xinjiang by Su et al. (2023b) demonstrated that industrial integration and structural upgrading significantly enhance farmers' income growth, indicating that institutional guidance fosters productive interactions between industrial policy and socio-economic structures, thereby facilitating inclusive innovation and income equity.

Simultaneously, social and institutional factors influence corporate decision-making within supply chain systems. Liu et al. (2024) found that differing equity reference points substantially affect collaboration among supply chain members, while institutionalized cooperation rules and social justice—key social psychological factors—directly determine sustainable innovation levels. At a broader level, Mahmood et al. (2024) emphasized that special economic zones, energy projects and sustainable infrastructure construction can deepen the interaction between economic resilience and green innovation by introducing sustainable supply chain management. These findings underscore the synergy between institutions and management practices in advancing sustainability. Similarly, in home healthcare, Du and Li (2024) integrated doctor-patient satisfaction with sustainability objectives to propose a multi-objective algorithm optimizing cost, carbon emissions, and service quality, illustrating the dual impetus of institutional management tools and social responsibility in service innovation.

From the consumption perspective, social responsibility and institutionalization are key drivers of sustainable consumption. For instance, Chen et al. (2024) revealed that information framing and social responsibility awareness significantly enhance consumer acceptance of "suboptimal food" in Indonesia, highlighting the pivotal role of social norms and institutional interventions in shaping green markets. At the corporate strategy level, Du et al. (2024) showed that green enterprises' decisions regarding technology openness, imitation, and investment are closely linked to market competition patterns and government subsidy policies. Open technology tends to improve social welfare and foster mutually beneficial "green" outcomes, further emphasizing the influential role of institutional incentives and market structures. Additionally, Liao et al. (2024) demonstrated that religious norms, as informal institutions, bolster corporate investment in environmental innovation, while media attention and industrial competition respectively amplify and attenuate these social norms' effects, illustrating the complex interplay between informal and formal institutions in driving corporate sustainable innovation.

Above all, the discussions in this section regarding the special issue articles are summarized in Table 5.

4 Conclusion

As a crucial approach to addressing climate change and environmental challenges, green transformation exhibits multidimensional characteristics driven by technological innovation and institutional forces. This study aims to systematically elucidate the interaction mechanism between technological innovation and institutional change during the green supply chain transformation process, thereby advancing the theory of green supply chain management and facilitating the coordination and mutual benefits between low-carbon economic development and ecological sustainability. Some research included in this special issue investigates key drivers and barriers to green transformation by constructing a comprehensive framework encompassing policy incentives, technology R&D, market orientation, and

Table 5 Details of the featured studies in social and institutional driving mechanisms of sustainable innovation

Authors and paper title	Method	Key insights
Ray et al. (2023). Sustainable farming practices adoption in agriculture supply chain: the role of indirect support versus cost subsidy	Analytical modeling	Compares cost subsidy vs. indirect support for natural farming adoption. Subsidy outperforms for high environmental damage; indirect support requires conscious farmers.
Su et al. (2023b). Examining the path of urban–rural industry convergence and its impacts on farmers' income growth: evidence from Xinjiang Uyghur Autonomous Region, China	Data analytics	Urban-rural industry convergence boosts farmers' income via industrial upgrading. Effects vary: positive for low-income groups, negative for high-income farmers. Digital economy impacts differ by region and income level in Xinjiang.
Liu et al. (2024). The effects of different fairness reference points on supply chain members' collaborative innovation	Analytical modeling	Fairness concerns make supply chain innovation decisions more conservative. Retailers benefit only with low innovation cost shares. Innovation levels vary by fairness reference point and bargaining power.
Mahmood et al. (2024). Sustainable infrastructure, energy projects, and economic growth: mediating role of sustainable supply chain management	Quantitative empirical modeling	SEZs, energy projects, and sustainable infrastructure boost economic resilience. SSCM and glocalization mediate these relationships, enhancing stability and growth. SEM analysis confirms foreign investment, diversification, and green logistics as key drivers.
Du and Li (2024). Multi-objective home healthcare routing and scheduling problem based on sustainability and "physician–patient" satisfaction	Analytical modeling	Optimizes home healthcare routing for cost, emissions, and patient/caregiver satisfaction. Proposes improved NSGA-III algorithm for multi-objective Pareto solutions. Outperforms existing algorithms in speed, convergence, and solution diversity.
Chen et al. (2024). Suboptimal food products in Indonesia: a sustainable consumption behavior choice experiment and unveiling the attributes with a causality approach	Qualitative empirical	Identifies key attributes for suboptimal food consumption via fuzzy DEMATEL. Socially responsible consumption and information framing drive sustainable behavior. Food waste avoidance and saving behavior enhance consumer acceptance.
Du et al. (2024). Green technology opening, imitation, and investment: firms' strategic technology choices in competitive markets	Analytical modeling	Green firms may open technology if market share transfer or green market size is large. Technology opening induces imitation but can create win-win outcomes and improve social welfare. Traditional firms imitate only when green technology is opened, balancing competition and trust gains.
Liao et al. (2024). How religious norms influence firms' environmental innovation? Evidence from China	Quantitative empirical modeling	Religious norms boost firms' environmental innovation via environmental ethics. Media attention strengthens this effect; industrial competitiveness weakens it

social participation. Collectively, these findings underscore the vital role of broad societal involvement.

Looking ahead, the green transformation of supply chains will increasingly emphasize the three-dimensional interaction among technology, institutions, and society. On the technological front, cross-disciplinary integration will be promoted, such as the convergence of artificial intelligence with the circular economy, and blockchain with green finance. Institutionally, policy instruments should consider regional differences and industry-specific characteristics. Socially, consumer behavior, corporate responsibility, and informal institutional factors will continue to shape the market environment, providing a broader social foundation for sustainable innovation. Therefore, future study on green transformation must be approached as a complex systems engineering challenge requiring multi-agent coordination, cross-level governance, and long-term dynamic optimization.

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