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Advancing sustainable supply chain management: emerging trends, challenges and determinants of success

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Abstract

Purpose – This study aims to provide a comprehensive framework for sustainable supply chain management (SSCM) by integrating environmental, social, economic and technological dimensions to bridge theoretical and practical gaps.

Design/methodology/approach – Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses methodology, a systematic review of 133 articles from the Scopus database was conducted, with qualitative analysis examining criteria such as SSCM, emerging technologies and sustainability.

Findings – The results reveal that SSCM drivers include government policies, stakeholder pressure, environmental concerns and managerial commitment, while challenges encompass high costs, technological complexity and data scarcity. Technologies like blockchain and the Internet of Things (IoT) enhanced transparency and efficiency.

Practical implications – The study offers industry-specific solutions and support for small and medium-sized enterprises in developing economies, though future research on resilience and social sustainability metrics is needed.

Originality/value – The study enriches the SSCM literature by emphasizing the triple bottom line approach, circular economy principles and models like 6 Rs and GreenSCOR.

Keywords Sustainable supply chain management, SSCM, Circular economy, Blockchain, Social sustainability, Challenges

Paper type Research article

1. Introduction

Sustainable supply chain management (SSCM) has become crucial for addressing global challenges such as climate change, resource scarcity and social inequality. Traditional linear supply chains, which often harm the environment, are being replaced by sustainable models incorporating circular economy principles, stakeholder collaboration and advanced technologies like artificial intelligence (AI), blockchain and the Internet of Things (IoT). Despite increased attention in academic and industrial fields, there remains a fragmented understanding and a lack of comprehensive frameworks that integrate environmental, social, economic and technological dimensions. This study addresses these gaps by proposing a holistic SSCM framework focused on bridging theoretical and practical divides. It examines five key research questions: how SSCM dimensions can be integrated into a comprehensive framework, what industry-specific implementation strategies exist, how advanced technologies enhance transparency and decision-making, what barriers hinder technology implementation and how theories can be effectively applied in practice. The paper introduces several innovations, including a multi-

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dimensional analytical framework, industry-specific solutions and practical guidelines for implementing models like 6 Rs and GreenSCOR. It also explores the role of advanced technologies like blockchain in enhancing transparency and overcoming implementation barriers. Additionally, it identifies emerging trends, such as the digital economy and cleaner production, while emphasizing the need for collaboration between policymakers, industry and academia. In summary, the study reviews the driving forces behind SSCM adoption, such as government policies, stakeholder pressures, environmental concerns and management commitment and addresses challenges like natural resource consumption and economic instability. It also compares SSCM models across industries, identifying both challenges and opportunities. Finally, it outlines the limitations of current models and suggests future research directions.

Given the growing awareness of environmental and social impacts, the transition to sustainable practices in supply chains is becoming increasingly important. Central to this transition is the concept of the sustainable supply chain (SSC), which integrates environmental, social and economic considerations into a unified framework (Jachimowski and Straka, 2024; Nagarjuna *et al*., 2023; Ramakrishna *et al*., 2024). Unlike traditional supply chains that prioritize cost and efficiency alone (Jedynak, 2023; Naidu *et al*., 2018), SSCs span the product lifecycle, sourcing renewable materials (Kazan and Ünal, 2023), employing eco-friendly production (Jachimowski and Straka, 2024; Ramakrishna *et al*., 2024) and leveraging reverse logistics for recycling (Jachimowski and Straka, 2024; Ayyildiz and Yildiz, 2023). Transparency and stakeholder collaboration further ensure sustainability standards are met (Nagarjuna *et al*., 2023; Ramakrishna *et al*., 2024), addressing climate change and resource scarcity by balancing these triple-bottom-line objectives.

2. Methodology

2.1 PRISMA framework and study eligibility

This study utilized the PRISMA framework for a systematic review of the literature on SSCM, chosen for its structured approach that ensures transparency, precision in defining inclusion and/or exclusion criteria and systematic analysis. This methodology helps reduce bias and allows for replication of the process, enhancing scientific credibility. The review process, depicted in Figure 1, involves multiple stages, from defining criteria to analyzing studies. The criteria for article selection were based on their relevance to supply chain management, emerging technologies, decision-making models and sustainability, ensuring scientific quality and credibility. All selected articles were in English and from reputable sources, with the detailed characteristics summarized in Table 1.

Additionally, to ensure comprehensive coverage, the Web of Science database was also consulted. All selected articles are indexed in Google Scholar, confirming their accessibility and credibility. The choice of Scopus as the primary database was due to its extensive coverage of peer-reviewed literature and its robust tools for extracting reference information, which were crucial for this systematic review.

Several key considerations guided the selection of inclusion and exclusion criteria to ensure the articles' relevance and scientific quality. Articles focused on SSCM, emerging technologies, challenges, analytical models and limitations were chosen to analyze recent trends and advancements. Sources in English from reputable journals ensured credibility, while a timeframe of 2019–2025 covered recent developments, supplemented by older articles for a solid theoretical foundation. As shown in Figure 2, the distribution of the selected articles across different years demonstrates a clear increase in the number of publications over time, with detailed counts provided for each year to highlight this trend. The inclusion of both final publications and preprints ensured data transparency and currency. The diversity of article types, such as research papers, book chapters, conference papers and reviews, provided a comprehensive perspective on innovative models in supply chains.

To ensure the inclusion of high-quality and thematically relevant sources in SSCM, a comprehensive and systematic search was conducted across reputable academic databases.

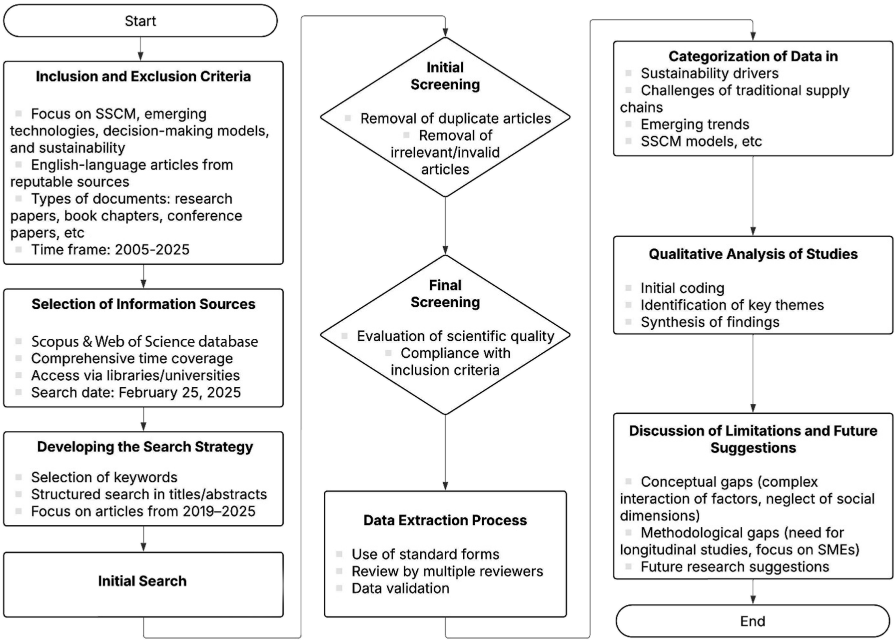

Figure 1. Process for article search and analysis. Source: Created by authors

Table 1. Characteristics of articles

No.	Criteria	Details
1	Timeframe considered	This study includes 133 articles published between 2005 and 2025. Specifically, 97 articles were published from 2019 to 2025, 29 articles from 2014 to 2018 and 7 articles before 2014
2	Language of articles	All 133 articles in this study are in English
3	Publication status of articles	One article is in the status of article in press, and 132 articles are in the status of final
4	Article types	The study includes 79 journal articles, 24 book chapters, 21 conference papers and 9 review articles

Source(s): Created by authors

Priority was given to peer-reviewed publications from well-established publishers to adequately cover both theoretical and practical aspects of the field.

As shown in Figure 3, the distribution of references by leading publishers illustrates the number of articles from each publisher used as references in this study, highlighting the breadth and depth of the selected literature. Key sources include journals such as the *Journal of Cleaner Production*, *Renewable and Sustainable Energy Reviews*, *Resources, Conservation and Recycling* and *Computers and Industrial Engineering*, as well as the *Annals of Operations Research*, *Environmental Science and Pollution Research*, *Institute of Electrical and Electronics Engineers (IEEE) Engineering Management Review*, *Business Strategy and the Environment* and *Production Planning and Control*, all of which strengthen the academic rigor and relevance of this review.

2.2 Information sources and search strategy

This section outlines the sources used for gathering articles in this study. The Scopus database was selected as the primary source due to its extensive coverage of credible scientific literature

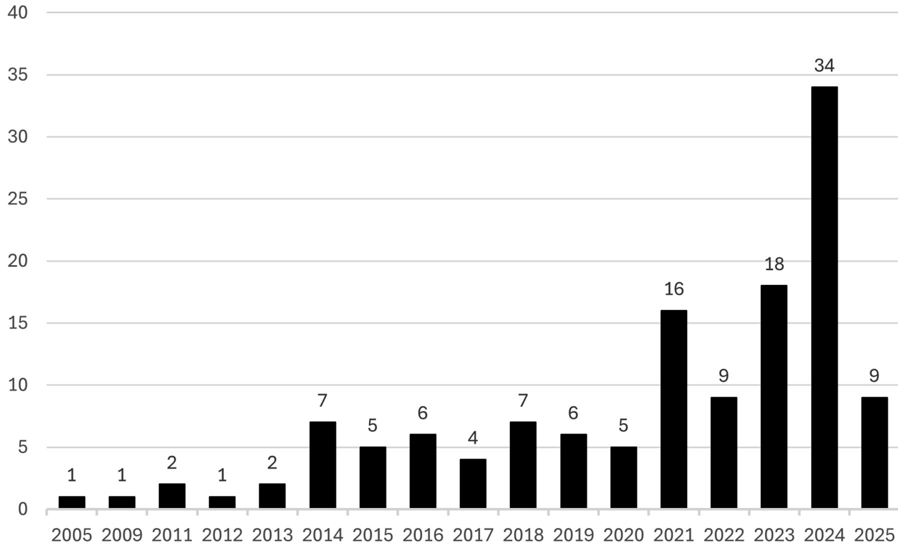

Figure 2. Distribution of selected articles by publication year. Source: Created by authors

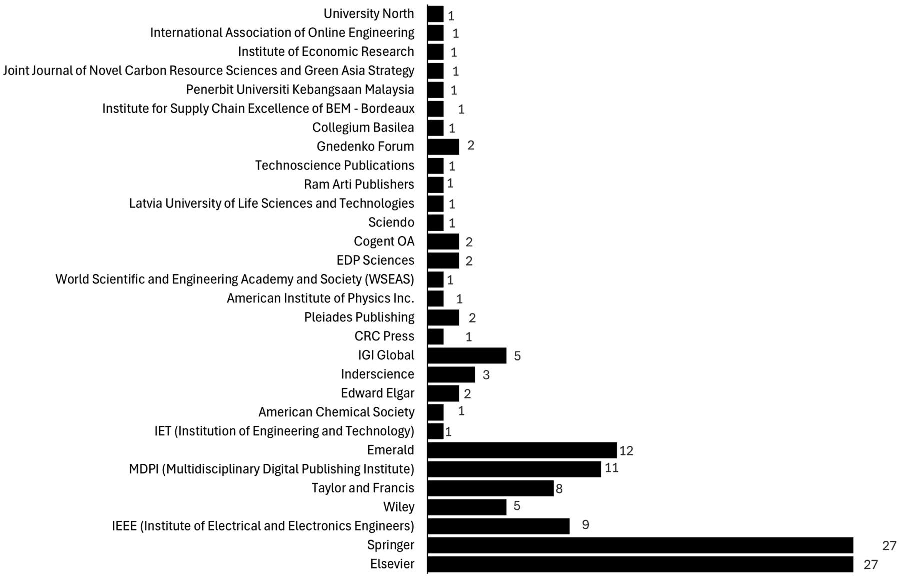

Figure 3. Number of references by publisher. Source: Created by authors

across different timeframes, ensuring access to high-quality and relevant publications in various disciplines. While Scopus was the primary database used for its comprehensive coverage and advanced search capabilities, supplementary searches were conducted in the Web of Science to ensure no relevant articles were missed. Additionally, Google Scholar was used to verify the indexing and accessibility of the selected articles. The decision to focus on Scopus was driven by its extensive collection of peer-reviewed literature and its efficient tools for managing and analyzing large sets of references, which were essential for this systematic review.

The database's scope, accessibility methods and the specific search date are detailed to enhance the research's reliability, accuracy and transparency. The criteria for the article selection process are summarized in Table 2.

This section describes the systematic approach used to identify relevant articles, focusing on supply chain management and emerging technologies. The strategy involved selecting specific keywords related to SSCM, circular economy, technologies like AI, blockchain, IoT, sustainability metrics, corporate social responsibility (CSR), green supply chain management (GSCM) and environmental sustainability. A structured search was conducted in scientific databases, prioritizing recent papers (2019–2025) while also incorporating older studies to provide a comprehensive overview. The process aimed to ensure a thorough search while maintaining alignment with the research objectives.

This section outlines the process of selecting credible evidence by screening articles from the Scopus database. A multi-stage approach was used to ensure scientific rigor and relevance to supply chains and new technologies. The process involved gathering articles, eliminating duplicates and irrelevant content and retaining only high-quality, relevant publications. Criteria for selection included English-language articles from reputable journals, while older and non-relevant works were excluded to maintain focus on new technologies.

2.3 Data items and selected studies

This section details the methodology for organizing and extracting data from 133 selected articles to explore sustainability in SSCM. Standardized forms and multiple reviewers ensured accuracy and validity through calibration and supervision, creating a reliable dataset. Data extraction, conducted independently by multiple individuals, included verification and validation to maintain integrity.

The selected articles were chosen for their relevance and importance in SSCM. To confirm their impact, citation counts were analyzed. Figure 4 presents a sample of citations along with each article's publication year, highlighting the academic influence of these sources.

The study systematically extracted data to analyze key aspects: drivers of sustainability transformation (government policies, stakeholder pressure, environmental concerns and innovation), challenges (environmental, economic and social barriers), trends (technological innovations and cleaner production), industry-specific needs (chemicals and logistics) and SSCM models (6 Rs and GreenSCOR). It compares model performance across industries like oil, gas and apparel, addressing challenges (initial costs, regulatory complexities and technology integration) and opportunities. Key variables were defined with clear references,

Table 2. Criteria for article selection

No.	Criteria	Details
1	Databases used	The primary database used for collecting articles was Scopus, selected for its credibility and broad coverage. Supplementary searches were also conducted in the Web of Science and Google Scholar to ensure comprehensiveness
2	Database time coverage	Scopus covers articles published across all timeframes, from the earliest records to the latest publications, and all relevant articles within this range were utilized for this research
3	Article accessibility	To access articles that were not directly available, the necessary subscriptions were obtained through libraries and universities
4	Search date	The latest search for updating articles and references was conducted on July 20, 2025

Source(s): Created by authors

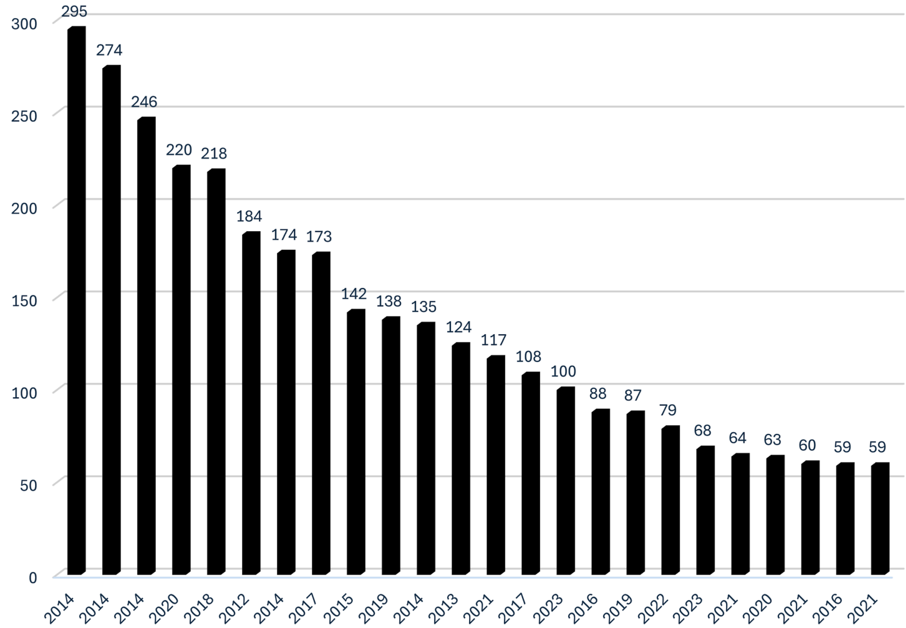

Figure 4. Article citations and year. Source: Created by authors

establishing a consistent analytical framework. Assumptions included stable operational environments, uniform resource and technology access, positive sustainability impacts, generalizable findings and linear models. Simplifications excluded regional diversity and social aspects, assuming uniform technology adoption. Limitations were acknowledged, with research gaps identified for future investigation.

The analysis of the 133 studies aimed to address 5 research questions, synthesizing findings to understand SSCM's economic, social, environmental and technological dimensions. A qualitative thematic analysis was employed for its ability to uncover patterns in diverse literature, exploring SSCM frameworks, industry-specific challenges, emerging technologies and implementation barriers. Unlike quantitative methods, this approach provided depth for complex conceptual questions. The process involved reviewing articles to derive themes like technological innovations, industry-specific pressures and implementation barriers, refined iteratively to align with research objectives. Insights were integrated into a narrative, supported by descriptive tables summarizing findings across industries. Thematic analysis handled diverse textual data, merging SSCM dimensions into a cohesive framework, addressing literature fragmentation and offering practical insights like technology adaptation strategies and sustainability drivers. Results were woven into the discussion to maintain coherence, emphasizing knowledge synthesis over procedural details.

3. Discussions

3.1 Drivers and challenges of sustainable supply chain management

SSCM is propelled by a complex interplay of external and internal drivers, including government policies, stakeholder pressures, environmental imperatives, internal motivations and strategic advantages. Regulatory frameworks in sectors like Indian electronics and real estate enforce sustainable practices (Menon and Ravi, 2021a, b; Koul and Roy Ghatak, 2024), while consumer demands, non-governmental organization advocacy and policymaker expectations, particularly in the automotive sector, foster green practices (Swami *et al*., 2020; Mathivathanan *et al*., 2018). Global challenges such as climate change and resource depletion further necessitate green supply chains (De Silva *et al*., 2022; Jum'a *et al*., 2022). Internally, top management commitment and corporate social responsibility enhance organizational reputation and sustainability outcomes (Menon and Ravi, 2021a, b; Kumar *et al*., 2023; Oelze *et al*., 2018; Jum'a *et al*., 2024). Strategic benefits, such as cost savings and competitive advantages, are evident in Ethiopian coffee and construction sectors, bolstered by innovations like those in Thai plastic packaging (Habib *et al*., 2024; Pintuma *et al*., 2024).

A critical analysis shows that internal drivers, such as managerial commitment, significantly mediate the impact of external pressures on sustainability. For example, regulatory compliance in Indian electronics relies on top management's sustainability focus, indicating that external mandates need internal support (Menon and Ravi, 2022; Emamisaleh and Rahmani, 2017). Similarly, customer and supplier pressures in the automotive sector are effective when paired with an innovative culture, as seen in Thai packaging's use of additive manufacturing (Swami *et al*., 2020). However, external pressures drive short-term compliance, while internal factors like leadership and cultural readiness foster long-term sustainability (Emamisaleh and Rahmani, 2017; Prashar and Sunder, 2025). This highlights a theoretical gap: the absence of frameworks modeling the dynamic interaction of internal and external drivers across industries, which future research could address with integrated models. Traditional supply chains face multifaceted challenges across environmental, economic and social dimensions. Environmentally, inefficient practices contribute to resource depletion, pollution and emissions (Taghikhah *et al*., 2019; Ayyildiz and Yildiz, 2023; Zijm and Klumpp, 2016; Ribeiro and Barbosa-Póvoa, 2021; Ramakrishna *et al*., 2024), prompting stricter regulations (Manenti, 2009). Economically, rising costs, market volatility and limited technological integration hinder efficiency (Suryawanshi and Dutta, 2020; Gattorna, 2016; Ryu and Pistikopoulos, 2005; Van Breedam, 2015; Georgise *et al*., 2013; Sharma *et al*., 2021). Socially, poor labor practices and ethical concerns necessitate fair standards (Kim and Davis, 2019; Gold and Wieland, 2024; Alizadeh Afrouzy *et al*., 2018; Betto *et al*., 2023; Alogla *et al*., 2021).

Social challenges, such as ethical labor practices, require long-term cultural transformation (Gold and Wieland, 2024). From an economic perspective, the high costs associated with green practices create significant barriers for small and medium-sized enterprises (SMEs) within Ethiopian coffee supply chains (Habib *et al*., 2024). In contrast, larger firms capitalize on eco-innovation to reduce costs and improve efficiency. This contrast highlights the resource limitations faced by SMEs that restrict their ability to implement SSCM, whereas larger organizations benefit from the economies of scale and technological innovation (Ullah and Lin, 2025). Notably, existing research lacks tailored strategies addressing the unique challenges of SMEs, indicating a critical area for future investigation.

To address these challenges, flexible, green and socially responsible models are essential (Abbasi and Nilsson, 2012; Abbasi, 2017; Bilan *et al*., 2020). Integrating sustainability into supplier selection, as seen in Indian electronics firms (Menon and Ravi, 2022), improves outcomes (Bhardwaj, 2014; Prashar and Sunder, 2025). However, success hinges on addressing tensions between external pressures and internal readiness, especially in SMEs where resource constraints limit innovation (Prashar and Sunder, 2025). A key research gap is the lack of studies on how SMEs can balance short-term compliance costs with long-term sustainability goals, indicating a need for sector-specific frameworks.

3.2 Trends and industry needs

SSCM models increasingly integrate technology, corporate social responsibility and cleaner production to achieve sustainability goals (Zotov, 2022; Pauliuk and Hertwich, 2015). Advanced tools like dynamic material flow analysis and Technology-Hybridized Environmental-Economic Model with Integrated Scenarios (THEMIS) support scenario planning (Todorov and Marinova, 2011; Solangi *et al*., 2025). Green finance, governance and urban sustainability, supported by renewable energy, further bolster these efforts (Nyandwe *et al*., 2024; Nauman *et al*., 2024; Blums *et al*., 2022; Ma *et al*., 2024). Performance assessment tools, such as key performance indicators, balanced scorecard and AI-driven fuzzy-analytic hierarchy process, are applied in the automotive and dairy sectors (Ferreira *et al*., 2016; Dvaipayana *et al*., 2021; Guo and Wu, 2023; Choudhary *et al*., 2025; Niranjan *et al*., 2025; Ghorbani *et al*., 2024).

Industries such as chemicals, manufacturing, mining, oil and gas, aerospace, food, automotive and logistics urgently require SSCM to address logistics inefficiencies, waste, emissions and resilience challenges (Golov *et al*., 2021a, b; Kusi-Sarpong *et al*., 2016; Afghah *et al*., 2023; Barbosa *et al*., 2019; Khot and Thiagarajan, 2024; Nawurunnage *et al*., 2023; Ibrahim *et al*., 2024; Ribeiro and Barbosa-Póvoa, 2021). The literature lacks comparative analyses of SSCM in knowledge-based industries like information and communication technology (ICT) or pharmaceuticals, limiting finding generalizability. Future research could explore applications in these non-traditional sectors.

3.3 Sustainable supply chain management models and comparative performance

SSCM models, such as the 6 Rs Model, mathematical and simulation models, green supply chain operations reference, closed-loop supply chains and conceptual frameworks, address lifecycle sustainability, efficiency, environmental integration, circularity and flexibility (Aarabi *et al*., 2011; Wofuru-Nyenke *et al*., 2023; Akkucuk, 2019; Sgarbossa and Russo, 2017; Zimon *et al*., 2019). These models support industries like manufacturing, food and textiles in meeting regulatory and market demands (Diabat *et al*., 2014). In India, adoption varies, with textiles lagging behind electronics and automotive due to weaker regulatory enforcement (Mathivathanan *et al*., 2019; Xu *et al*., 2013). Quantitative methods, such as mixed integer linear programming and analytic hierarchy process, optimize costs and emissions (Becerra *et al*., 2021; Pandey *et al*., 2021), while green logistics and remanufacturing enhance sustainability (Nikseresht *et al*., 2024; Chardine-Baumann and Botta-Genoulaz, 2014).

A comparison of SSCM models reveals their strengths and limitations. The 6 Rs Model and closed-loop supply chains promote circularity in plastics but often neglect social dimensions (Moreira *et al*., 2022; Rebs, 2018). Green supply chain operations reference, used in oil and gas, emphasizes environmental integration but overlooks social factors (Beiranvand *et al*., 2022). Quantitative models like mixed integer linear programming optimize economic and environmental outcomes but undervalue social aspects (Becerra *et al*., 2021; Rebs, 2018). Conversely, stakeholder and institutional theory-based frameworks in Bangladesh's garment industry integrate economic, environmental and social dimensions through stakeholder engagement (Karmaker *et al*., 2023; Peng *et al*., 2022). However, effectiveness varies; weaker regulatory enforcement in Indian textiles hampers SSCM adoption compared to electronics (Mathivathanan *et al*., 2019; Bhardwaj, 2014). A research gap exists in comparing the methodological rigor of these models (e.g. sample size and data quality) to enhance their applicability.

SSCM models improve performance across sectors: green logistics in oil and gas (Beiranvand *et al*., 2022), multi-objective optimization in dairy (Validi *et al*., 2014), resource efficiency in plastics (Moreira *et al*., 2022), eco-innovation in Pakistan's industries (Siddiqi *et al*., 2025) and Industry 4.0 in Bangladesh's garments (Karmaker *et al*., 2023). A critical analysis shows that internal drivers, like leadership commitment, are crucial for SSCM (Mathivathanan *et al*., 2019), but barriers such as financial constraints and inadequate information technology infrastructure, especially in India's textile SMEs, limit adoption (Xu *et al*., 2013; Emamisaleh and Rahmani, 2017; Prashar and Sunder, 2025). Externally, regulatory pressures drive SSCM in oil and gas (Beiranvand *et al*., 2022), but complex regulations hinder agriculture (Bhardwaj, 2014). While external drivers spur immediate action, internal readiness ensures long-term success (Emamisaleh and Rahmani, 2017; Prashar and Sunder, 2025). Stakeholder-focused models offer competitive advantages but need comprehensive frameworks addressing all triple bottom line dimensions (Karmaker *et al.*, 2023; Lüdeke-Freund *et al.*, 2017; Rebs, 2018; Chardine-Baumann and Botta-Genoulaz, 2014).

3.4 Challenges in sustainable supply chain management

3.4.1 Key obstacles. SSCM implementation faces economic, social, environmental, technological, operational and strategic challenges. Economically, high upfront costs and delayed returns, particularly for SMEs, impede adoption (Alhindawi *et al.*, 2025; Gonçalves *et al.*, 2024). Socially, insufficient stakeholder awareness and resistance to change demand strong leadership (Alhindawi *et al.*, 2025; Gonçalves *et al.*, 2024; Abbasi and Nilsson, 2012). Environmentally, fragmented regulations and inadequate metrics complicate compliance and performance measurement (Alhindawi *et al.*, 2025; Gonçalves *et al.*, 2024; Santiteerakul *et al.*, 2015; Ahi and Searcy, 2015). Technologically, the lack of standardized SSCM models and high costs of technologies like blockchain hinder progress (Ahi and Searcy, 2015; Moroni *et al.*, 2024; Tzanetou *et al.*, 2025). Operationally, managing sustainable practices across diverse supply chain activities and balancing resilience with sustainability is challenging (Santiteerakul *et al.*, 2015; Giri and Singh, 2024; Alam *et al.*, 2023; Mari *et al.*, 2014). Strategically, aligning sustainability with business goals and ensuring collaboration is resource-intensive (Aray *et al.*, 2021; Rezaei Vandchali *et al.*, 2021).

A comparative analysis highlights sector-specific barriers to SSCM. High costs and regulatory unawareness dominate in the cold food supply chain (Ghadge *et al.*, 2021), while textiles face communication gaps and limited reverse logistics (Vishwakarma *et al.*, 2022). Agriculture equipment manufacturing grapples with design complexity and emissions (Chaudhari *et al.*, 2024). Tailored solutions, like blockchain for agriculture traceability (Chaudhari *et al.*, 2024) and improved communication in textiles (Vishwakarma *et al.*, 2022), are needed. Common barriers, such as high costs and technical expertise shortages, disproportionately impact SMEs, hindering SSCM adoption compared to larger firms (Zain *et al.*, 2024). However, large enterprises face complex supply chains and stakeholder pressures (Prabhuswamimath *et al.*, 2024; Panigrahi and Rao, 2018). A research gap exists in longitudinal studies on how these barriers evolve, which could guide dynamic SSCM strategies.

Big data analytics, constrained by data availability (Stefanovic *et al.*, 2025; Mageto, 2021), can be supported by solutions like digital product passports for data sharing (Heeß *et al.*, 2024) and modeling to address data gaps (Sharma and Tewari, 2024). Cross-functional teams and supportive policies further enhance data-driven sustainability (Sharma and Tewari, 2024; Gupta *et al.*, 2020; Menon and Ravi, 2021a, b). In capital-intensive sectors like construction, high initial costs deter SSCM adoption, though green practices yield long-term savings (Habib *et al.*, 2024; Mankar *et al.*, 2024). Green practices not only reduce operational costs but also improve overall performance, thus enhancing the business case for SSCM adoption (Waqas *et al.*, 2023). In sectors such as manufacturing, the adoption of SSCM is further challenged by technical barriers and the upfront cost of implementing eco-design and green logistics solutions. However, these practices have been shown to improve operational efficiency and long-term performance, making them increasingly attractive despite initial resistance (Epoh *et al.*, 2024).

Big data analytics and cloud computing enhance SSCM by improving decision-making, optimizing resources and reducing adoption barriers, making sustainable practices more feasible (Jain *et al.*, 2024; Talatappeh and Lakzi, 2020). A comparison of SSCM effectiveness reveals sector-specific factors. In healthcare, lean supply chain management boosts cost performance but faces cultural barriers in Jordan (Bialas *et al.*, 2023; Ezmigna and Omain, 2024). The food industry leverages white supply chain management driven by social pressures (Suksanchananun *et al.*, 2024). Angola's retail and transportation prioritize economic goals through green supply chain management, despite environmental aims (Liahuka and Piricz, 2023). Chinese manufacturing shows SSCM improves performance (Xia and Kamoshida, 2015), but SMEs face resource constraints (Zain *et al.*, 2024; Machado *et al.*, 2021; Prabhuswamimath *et al.*, 2024).

The triple bottom line framework justifies SSCM by integrating financial, environmental and social metrics (Presley and Meade, 2018; Arampantzi and Minis, 2017), with regulatory pressures making SSCM increasingly necessary (Tseng and Hung, 2014; Xie, 2016).

3.4.2 The role of emerging technologies. Emerging technologies like blockchain and IoT enhance SSCM transparency and traceability. Blockchain provides immutable records for compliance and trust (Pal, 2023a, b; Chauhan and Sahoo, 2024), while IoT enables real-time monitoring of resource use, improving efficiency (Pal, 2023a, b; Chauhan and Sahoo, 2024; Talpur *et al*., 2023). AI and machine learning optimize demand forecasting and resource utilization, reducing costs and waste (Ojha *et al*., 2021; Olga, 2024; Ermolovskaya *et al*., 2024). High costs and complexity limit SSCM adoption, particularly in SMEs (Chauhan and Sahoo, 2024; Zhen and Yao, 2024). SMEs face technical expertise shortages for blockchain and IoT adoption in Indian manufacturing (Chauhan and Sahoo, 2024; Zain *et al*., 2024), though Indian manufacturers integrate triple bottom line objectives using emerging technologies (Yogi and von Rosing, 2024). Large enterprises, despite legacy system challenges, effectively leverage technologies, as seen in China's heavy vehicle industry (Chaudhari *et al*., 2024; Pereseina *et al*., 2014). Lifecycle solutions and partnerships enhance sustainability and safety (Pereseina *et al*., 2014). In food supply chains, blockchain improves traceability but faces regulatory hurdles (Ghadge *et al*., 2021), yet reduces waste and enhances safety (Ellahi *et al*., 2024). While blockchain fosters trust (Pal, 2023a, b), privacy concerns persist (Chauhan and Sahoo, 2024), necessitating standardized frameworks for transparency and security (Zain *et al*., 2024). Training and targeted policies could address SME barriers.

3.5 Limitations

3.5.1 Conceptual gaps. The current research on sustainable supply chains reveals several important gaps. Although various drivers like government policies, stakeholder pressures, environmental concerns and senior management commitment are acknowledged, their interactions, especially across different industries or regions, remain underexplored. For example, the combined impact of stakeholder pressure and government policies on decision-making in sectors like automotive versus mining has not been fully investigated (Kanellos, 2024; Gupta *et al*., 2020). Moreover, many studies focus mainly on large, traditional industries, neglecting the unique challenges faced by less-developed industries in low-income countries, including inadequate infrastructure, corruption and a lack of skilled labor. Emerging sectors, such as ICT and pharmaceuticals, face challenges like electronic waste and high energy consumption that are underexplored (Heeß *et al*., 2024). Additionally, the combined efficiency of sustainability models, like GreenSCOR integrated with circular economy principles, or new tech-driven models like AI and blockchain, has not been comprehensively assessed (Mageto, 2021).

Emerging technologies, such as blockchain for transparency, AI for disruption prediction and IoT for monitoring, have not been fully explored in the context of sustainable supply chains (Stefanovic *et al*., 2025). The impact of the digital economy and urban sustainability, particularly on urban logistics, also requires further investigation. Geopolitical disruptions like sanctions and trade wars, which can significantly affect sustainable supply chains, have not been adequately addressed (Sharma and Tewari, 2024). Moreover, most existing models focus primarily on economic and environmental factors, neglecting the social dimension of sustainability, including fair labor practices, human rights and community impact (Menon and Ravi, 2021a, b). Longitudinal and comparative studies that examine the evolution and performance of sustainability models across industries and regions are essential for deeper insights into their long-term effectiveness (Sharma and Tewari, 2024).

Furthermore, the barriers and enablers for SMEs in adopting sustainability models, particularly in emerging economies, are underexplored. The current models also fail to integrate risk management and resilience strategies, which are crucial in addressing crises such as pandemics or climate change. The integration of circular economy principles into supply chains and life cycle assessments remains underdeveloped (Gupta *et al.*, 2020). Lastly, sectors like ICT and pharmaceuticals, which face challenges such as electronic waste and ethical concerns, are still underrepresented in sustainability research. Increased focus on these sectors is vital for advancing comprehensive sustainability frameworks across industries (Mageto, 2021).

3.5.2 Future research. To advance SSCM and address identified conceptual and practical gaps, the following research directions are proposed. These build on internal and external drivers, challenges and trends, offering evidence-based pathways integrating economic, environmental and social dimensions. Each suggestion includes operational examples and implementation methods for practical applicability, addressing industry-specific frameworks, social metrics and technological integration, while overcoming barriers in developing countries and SMEs.

(1) Develop industry-specific hybrid models integrating economic, environmental and social dimensions. Holistic frameworks could combine models like the 6 Rs Model and green supply chain operations reference with stakeholder and institutional theory, as seen in Bangladesh's garment industry (Karmaker *et al.*, 2023). For example, in Indian electronics, a model could incorporate circular economy principles like recycling with stakeholder engagement for cost optimization and fair labor practices (Menon and Ravi, 2022), using mixed integer linear programming to optimize resources and include social metrics like worker safety scores (Rebs, 2018). Pilot projects in automotive could use IoT sensors for real-time environmental monitoring, aligning with regulations (Swami *et al.*, 2020).

(2) Design tailored strategies for SMEs in developing countries, where resource constraints hinder adoption, as in Ethiopian coffee or Indian textiles (Habib *et al.*, 2024; Xu *et al.*, 2013). Low-cost models using local resources, like recycled packaging or community-based suppliers, could reduce costs. Lean practices from Jordan's healthcare sector could track sustainability metrics like waste reduction (Bialas *et al.*, 2023). Pilot projects in Ethiopian coffee supply chains could collaborate with cooperatives to enhance social sustainability and address barriers like corruption.

(3) Develop social sustainability indicators for labor-intensive sectors like textiles and agriculture (Rebs, 2018). Metrics like fair labor scores or supplier diversity could be quantified using a scorecard approach, as in automotive and dairy sectors (Ferreira *et al.*, 2016). Stakeholder workshops in Bangladesh's garment industry could define metrics like ethical sourcing standards (Karmaker *et al.*, 2023), aligning with local contexts and the triple bottom line (Presley and Meade, 2018).

(4) Propose frameworks for integrating technologies like blockchain, IoT and AI to enhance transparency and efficiency (Pal, 2023a, b; Chauhan and Sahoo, 2024). In food supply chains, blockchain-based digital product passports could improve traceability (Heeß *et al.*, 2024). Pilot projects in Indian manufacturing could use IoT for real-time resource monitoring and AI for waste reduction (Ojha *et al.*, 2021). Public-private partnerships could address cost barriers (Nyandwe *et al.*, 2024).

(5) Conduct multi-year studies comparing traditional sectors like automotive with emerging ones like ICT and pharmaceuticals; compare green supply chain operations reference in oil and gas with AI-driven models in ICT, using metrics like cost savings (Beiranvand *et al.*, 2022), and case studies with standardized data collection could address data quality gaps (Heeß *et al.*, 2024).

(6) Develop models embedding risk management for crises like pandemics (Sharma and Tewari, 2024). Resilience metrics, like recovery time, could integrate into closed-loop supply chains. In oil and gas, scenario planning with material flow analysis could test

strategies (Todorov and Marinova, 2011). Simulation-based training could align with environmental goals (Giri and Singh, 2024).

(7) Advance life cycle assessment models incorporating circular economy principles like recycling across supply chain stages. In plastics, assess closed-loop systems (Moreira *et al.*, 2022). Industry partnerships could pilot reverse logistics in textiles (Vishwakarma *et al.*, 2022).

(8) Investigate how drivers like regulations and managerial commitment interact across contexts like automotive versus mining (Kanellos, 2024). Agent-based modeling in Indian electronics could simulate these interactions (Menon and Ravi, 2022). Cross-industry surveys could provide context-specific insights.

These directions offer actionable, industry-relevant recommendations with operational examples like pilot projects and implementation methods like partnerships, addressing study insights and ensuring practical relevance across sectors.

4. Conclusions

This study provides a comprehensive analysis of the drivers, challenges, models and trends in SSCM, offering deep insights into the complexities of transitioning to sustainable supply chains. Its key contributions include identifying the multifaceted interplay between external pressures, such as government policies and stakeholder expectations and internal motivations, like top management commitment, highlighting the pivotal role of policy and leadership in advancing sustainability alongside strategic benefits like competitiveness and economic efficiency. Theoretically, it enriches SSCM frameworks by emphasizing the triple bottom line approach (economic, environmental and social) and extends the concept of resilience through the integration of emerging technologies like blockchain, IoT and the digital economy, though the lesser focus on social sustainability underscores the need for further theoretical development. Practically, the findings offer actionable insights for managers and policymakers, including leveraging technology for transparency and efficiency, tailoring models to specific industries (e.g. automotive and logistics) and promoting financial incentives like green financing, particularly beneficial for SMEs in developing economies. However, limitations such as the incomplete exploration of driver interactions, a focus on large traditional industries over emerging or less-developed sectors and the lack of longitudinal studies and comprehensive social metrics restrict the generalizability of the findings, while data scarcity and privacy concerns further complicate technology assessments. To address these gaps, future research should prioritize hybrid models, analyze barriers in developing countries and integrate circular economy principles and transformative technologies to ensure SSCM effectively meets diverse industry and regional needs. Proposed research directions address identified gaps through industry-specific hybrid models, tailored strategies for SMEs in developing countries and operational frameworks integrating social sustainability metrics and technologies like blockchain and AI. These recommendations support effective SSCM implementation across economic, environmental and social dimensions. Overall, this study illuminates the path to sustainability and provides a roadmap for future research, making a significant contribution to advancing both the knowledge and practice of SSCM.

Building on this foundation, SSCM emerges as a critical strategy for addressing the environmental, social and economic challenges of the modern world. Through an extensive literature review and the development of an integrated framework, this study underscores the need to shift from traditional linear supply chain models to sustainable ones grounded in circular economy principles, multilateral collaboration and advanced technologies such as AI, blockchain and the IoT. This multi-dimensional framework provides a holistic perspective that overcomes the fragmented approaches of previous models, paving the way for practical implementation in industries like automotive, logistics and chemicals. The findings highlight the importance of aligning SSCM strategies with the unique characteristics of each sector. Advanced technologies play a transformative role: blockchain improves traceability, IoT enables real-time monitoring and AI optimizes demand forecasting. However, barriers such as high initial costs and technological complexities, particularly for SMEs, pose challenges that require increased investment in research and development and the establishment of standardized regulations. Emerging trends like the digital economy and cleaner production further accelerate SSCM adoption. Ultimately, the success of SSCM depends on robust collaboration among policymakers, industry leaders and academia to foster innovation, ensuring a sustainable future that balances economic success with environmental and social responsibilities.

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