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Implementation and Challenges of Emission Trading Mechanisms in Sustainable Supply Chain Management: A Bibliometric-Based Systematic Literature Review of the Manufacturing Sector

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Abstract

Purpose – The increasing pressure to reduce carbon emissions has made emissions trading mechanisms a crucial policy instrument in Sustainable Supply Chain Management (SSCM), particularly in the manufacturing sector. This study aims to systematically examine the implementation of emissions trading mechanisms in manufacturing supply chains and identify key challenges and mitigation strategies related to the cost-emissions trade-off.

Methodology – This study employed a mixed-methods approach, combining bibliometric analysis and a systematic literature review (SLR) based on the PRISMA framework. Data were obtained from the Scopus database, comprising 227 journal articles published between 2001 and 2024.

Findings – The findings reveal a paradigm shift from static models toward dynamic, data-driven, and multi-objective approaches. Moreover, the results confirm that the cost–emission trade-off is not inherent but is shaped by model design, power structures within supply chains, and the alignment of policy frameworks with managerial capabilities.

Originality – This study offers original insight by integrating bibliometric mapping with a systematic qualitative synthesis to examine the implementation and challenges of emission trading mechanisms within sustainable supply chain management in the manufacturing sector.

Research limitations – Articles analyzed in this study are limited to publications in Scopus database during 2001-to-2024 time span.

Practical implications – This study emphasizes the importance of integrating carbon policies with optimization technologies and strengthening managerial capabilities. Suggestions for further research include testing the identified models in empirical contexts across countries and industries, and developing dynamic frameworks that simultaneously incorporate policy uncertainty, actor behavior, and technological evolution.

Introduction

In recent years, industrial processes have increasingly leveraged advanced technologies, enabling the production of more complex goods while intensifying environmental pressures. Industrial activity is a major contributor to global carbon emissions, which are closely

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associated with climate change and tend to be concentrated in urban areas shaped by development patterns, infrastructure expansion, and technological progress (Wei et al., 2024). Corporate operations, including the adoption of new technologies and innovations, can further elevate emission levels. During the COVID-19 pandemic, industrial carbon emissions temporarily declined as restrictive policies reduced production activity in 2020. However, with the easing of restrictions and economic recovery in 2021, emissions rose again, underscoring the continued role of the industrial sector as a significant source of carbon emissions (Erőss & Pálvölgyi, 2024).

At the global level, carbon dioxide emissions from fossil fuels and industrial activities reached 37.41 billion tons in 2024, representing an increase of more than 60% compared to 1990 levels (Tiseo, 2025). In developing economies, globalization has further amplified emissions through expanded trade and industrial output (Sinha, 2023). China has been identified as the world's largest greenhouse gas emitter, largely due to rapid economic growth and industrialization (Tiseo, 2025). Rising emissions and mounting environmental pressures have prompted firms to reassess and restructure their supply chain operations, with increasing emphasis on reducing carbon emissions while maintaining profitability (Qu et al., 2013). These efforts, commonly referred to as decarbonization, and position supply chain decarbonization as an integral component of contemporary supply chain management.

The principle of decarbonization, or carbon emission deficit, is part of a company's strategy aligned with the principles of the Paris Agreement, an agreement between 195 countries to achieve net-zero emissions by the mid-21st century (United Nations Climate Change, 2015). These carbon policies include carbon taxes, cap-and-trade frameworks, and the establishment of maximum emission limits to reduce carbon emissions in the supply chain. These policies encourage companies to invest in environmentally friendly technologies and restructure supply chains to reduce costs and emissions (Tat et al., 2023). Supported by a McKinsey study, researchers Bové & Swartz (2016) revealed that companies need to reduce carbon emissions per unit of production by 2050. One effort to improve environmental performance by reducing gas emissions from industrial production and operations is the implementation of decarbonization in sustainable supply chain management (Mugoni et al., 2024). These emission mitigation efforts require a transition from primary and secondary industries to the tertiary sector through adjustments to the allocation structure within the supply chain. Restructuring the structure of production and final demand has been shown to reduce emissions at lower production levels, thereby supporting overall emission reductions through supply chain efficiency and the development of clean technologies (Li et al., 2024).

A study by Changalima et al. (2025) entitled "Trending Research Topics on Carbon Footprint and Supply Chains: A Bibliometric Analysis Based on the Scopus Data (2019–2023)" shows that bibliometric studies related to carbon footprint and supply chains have attracted attention in recent years. Despite its contributions, this study has several methodological limitations that present opportunities for future research. First, the limited time span of the reviewed publications (2019–2023) may reduce the representativeness of the findings with respect to long-term research developments and historical transformations in supply chain decarbonization. Second, the exclusive use of English-language publications introduces potential language bias, as relevant contributions published in other languages may have been overlooked. Consequently, further systematic literature reviews grounded in bibliometric findings are needed to capture a more comprehensive research landscape on sustainable supply chain management and carbon emissions.

In response to these gaps, this study addresses the research question: *How are emission trading mechanisms implemented, and what challenges arise in the practice of sustainable supply chain management within the manufacturing sector?* Accordingly, the scope of the review is confined to the integration of emission trading mechanisms into supply chain decision-making in manufacturing industries, enabling an in-depth examination of implementation challenges and associated managerial implications in high-emission contexts.

Research Methods

This study adopts a mixed-review approach that integrates bibliometric analysis with a systematic literature review (SLR) to provide a comprehensive overview of research on sustainable supply chain management and carbon emissions. This approach allows for the objective analysis of a large body of literature while enabling in-depth examination of conceptually and methodologically relevant themes. In line with established methodological guidance, bibliometric analysis was used as an initial mapping stage, followed by SLR-based qualitative synthesis (Donthu et al., 2021). The study is structured as a literature review of international journal articles in the fields of business and management, covering publications from 2002 to 2024 to capture the longitudinal development of the research domain. Bibliographic data were retrieved from the Scopus database due to its broad coverage and standardized metadata suitable for bibliometric analysis.

The search process was conducted using keywords in the title, abstract, and article keywords through the following query: TITLE-ABS-KEY ("sustainable supply chain management" AND "carbon emission") AND PUBYEAR > 2001 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, "BUSI")) AND (LIMIT-TO (DOCTYPE, "ar")). The initial screening yielded 227 journal articles that met the search criteria. All documents were in the final publication stage and published in reputable journals.

A bibliometric approach was employed in the first stage with the aim of mapping the intellectual structure and research development at a macro level. Bibliometric analysis included an evaluation of publication performance (number of articles, annual trends) and science mapping to identify patterns of relationships between topics and thematic clusters (Aria & Cuccurullo, 2017). Bibliometrics is used as an exploratory tool to systematically manage a large corpus of literature and reduce the potential for subjective bias in the initial stages of the review (Donthu et al., 2021). The initial processing used Microsoft Excel 365, specifically to streamline the metadata structure of the Scopus export results. Vosviewer is software developed by van Eck and Waltman to build and visualize bibliometric networks, such as co-authorship, co-citation, and keyword co-occurrence (Yıldız & Karakuş Yılmaz, 2024).

This software is used to view relationships between authors, institutions, and research topics and group them based on the resulting clusters. There is no rule for determining the appropriate cluster size, but it is recommended to set a minimum threshold of 10% of the total document sample size (Marzi et al., 2025). The analysis results are presented in cluster figures and graphs. Vosviewer visualizes the analysis results in three types: network, density, and overlay analysis (Marzi et al., 2025). The bibliometric analysis then produces key thematic clusters that represent the dominant research focuses in the literature on sustainable supply chain management and carbon emissions. These clusters served as the basis for further selection for in-depth analysis. After the primary clusters were identified, the study continued with a

systematic literature review (SLR) of the selected clusters using the latest version of the **PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)** framework**.** PRISMA was implemented to ensure transparency, reproducibility, and traceability of the study selection process (Page et al., 2021).

Tabel 1. PICOS Framework

PICOS Framework	Inclusion	Exclusion
Screening Stage		
Population	Articles focusing on the high-emission manufacturing sector	Studies in the service, banking, or agricultural sectors do not directly represent the manufacturing SCM context.
Intervention	Implementation of emissions trading (cap-and-trade) mechanisms in sustainable supply chain management and decision-making	Articles that solely discuss mathematical optimization without a carbon policy context, or articles that discuss RE from a macroeconomic perspective without any connection to SCM, are excluded.
Eligibility Stage		
Outcome	Articles present qualitative findings related to managerial challenges, policy implications, or sensitivity analysis of models relevant to business practice (why and how).	Studies that only present pure mathematical modeling without empirical validation or without discussion of practical implications
Study Design	Journal articles use quantitative studies based on field data with the status ***Open Access***.	Review articles (SLR/mapping), conference proceedings, and non-Open Access articles

The PRISMA steps include a) **identification**, which collects articles from selected clusters based on bibliometric analysis; b) **screening**, which assesses the suitability of titles and abstracts to the research objectives; c) **eligibility**, which examines the full text to ensure conceptual and methodological relevance and contribution to the study topic; and d) **inclusion**, which determines the final articles for in-depth analysis. This approach follows SLR best practices, which emphasize thorough literature screening and consistent inclusion and exclusion criteria (Tranfield et al., 2003).

Articles that pass the inclusion stage are analyzed qualitatively through thematic synthesis (Ren et al., 2019). The analysis focuses on identifying conceptual patterns, methodological approaches, and key findings related to carbon emissions management in sustainable supply chains. Theoretical frameworks and findings from previous research are used as a basis for interpretation to ensure analytical depth and interrelationships between studies. Research validity is maintained through the use of standard protocols (bibliometric and PRISMA) and reputable databases. Reliability is strengthened by the application of consistent and replicable selection criteria. This research does not directly involve human subjects, so it does not require special ethical approval, and all sources used are publicly available scientific publications.

Results and Discussion

Bibliometric Analysis

The bibliometric analysis found research data related to sustainable supply chain management and carbon emissions based on collaboration patterns between authors and institutions. Analysis was conducted to examine interconnectedness of actors, identify key researchers or institutions, and map the distribution of collaboration in the development of this field of study.

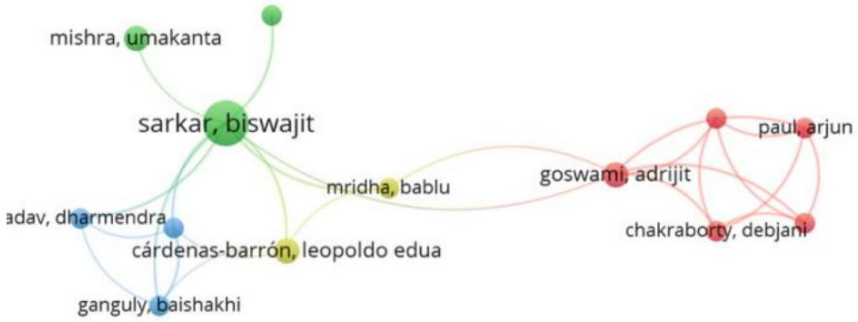

Figure 1. Visualization of the Collaboration Network between Authors
Source: (Data Processing)

Based on Figure 1, a visualization of the results of the collaboration network analysis between authors using VOSviewer, it can be interpreted that of the 697 authors identified on the topic of sustainable supply chain management and carbon emissions, previous research recommends setting a threshold of 10% of the total publications found (Marzi et al., 2025).

Table 2. Percentage of Author Publications in Publications

No.	Author	Total Document	Total Citations	%
1	Biswajit Sarkar	10	1,096	17.24
2	Fred I. Allen	2	45	3.45
3	Amanda J. Ashworth	2	45	3.45
4	Adrijit Goswami	2	183	3.45
5	Patrick D. Keyser	2	45	3.45
6	Daniell Reed	2	45	3.45
7	Adam M. Taylor	2	45	3.45
8	Donald D. Tyler	2	45	3.45
9	Debjani Chakraborty	2	134	3.45
10	Ravi Shankar Kumar	2	134	3.45

Source: (Data Processing)

In this study, 58 authors met the minimum threshold of two publications; however, only 13 of them were interconnected within a collaborative network. While a well-established network typically reflects active and productive collaboration, the findings indicate relatively limited author collaboration in this field. The resulting network appears fragmented, which may hinder the diffusion of new ideas due to restricted connectivity among knowledge actors (Powell et al., 1996). As shown in Table 1, Biswajit Sarkar emerged as the most prominent collaborator in terms of publications and citations, whereas most other authors operated independently with minimal linkage. Strengthening collaboration across institutions and countries could enhance knowledge exchange by creating weak ties that facilitate the spread of innovation in sustainable supply chain management (Granovetter, 1973). Overall, although some cohesive research groups exist, collaboration across authors remains uneven.

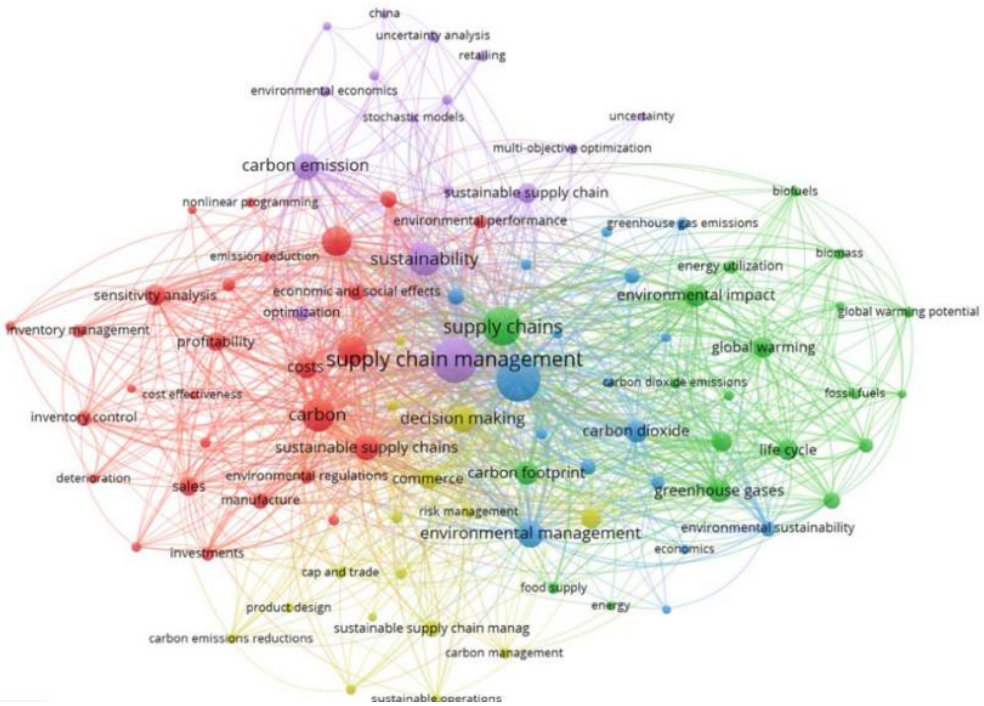

Figure 3. Network Visualization of Keyword Network Related to Sustainable Supply Chain Management and Carbon Emissions
Source: (Data Processing)

Figure 3 shows a network visualization to identify current research trends. Through keyword analysis using VOSviewer, 1,848 keywords were identified across all analyzed documents. After applying a threshold of five minimum occurrences, 96 related keywords were filtered and formed a collaborative network. This threshold was determined by a minimum of 10% of the total articles analyzed (Marzi et al., 2025). In this study, the bibliometric analysis yielded five main clusters representing the development of topics in SSCM studies related to carbon emissions. Each cluster reflects a different focus yet complements each other in forming a comprehensive understanding of the research landscape in this field.

In the bibliometric analysis of the SSCM and carbon emissions literature, the keyword "Supply Chain Management" (SCM) emerged as the most dominant term, occupying the top spot with 115 occurrences. This frequency of occurrence indicates that SCM is a focus of academic discourse, both as a conceptual foundation and as an object of practical application in SSCM related to carbon emissions. Conceptually, SCM refers to the integrated management of the flow of goods, information, and finances in production and distribution. SSCM is an SCM concept with a sustainability approach, encompassing economic, social, and environmental aspects (Payán-Sánchez et al., 2021). From a practical perspective, SCM directly contributes to improved operational efficiency, environmental performance, and the effectiveness of supply chain management decision-making.

The high occurrence of this keyword in bibliometric research indicates that researchers are actively examining the role of SSCM, particularly in relation to carbon emissions from company and industry operations, which are a consequence of the threat of global warming (Ghadge et al., 2020; Manan & Alwi, 2015). This aligns with literature studies related to SCM implementation practices designed to address carbon emission policies within an omni-channel distribution strategy, resulting in accelerated digital transformation and collaboration between parties within the SCM ecosystem (Mafia et al., 2022).

Table 3. Top 10 Keywords in Each Cluster

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
carbon emissions	*agriculture*	*carbon dioxide*	*cap and trade*	*carbon emission*
closed-loop supply chain	*biofuels c*	*Circular economy*	*carbon emissions reduction*	*china*
cost benefit analysis	*biomass*	*co2 emission*	*carbon management*	*emissions trading*
cost effectiveness	*carbon dioxide emission*	*developing countries*	*climate change*	*environmental economics*
cost reduction	*carbon footprint*	*economics*	*economic analysis*	*manufacturing*
emission control	*decision support system*	*environmental management*	*energy efficiency*	*multi-objective optimization*
emission reduction	energy	*environmental protection*	*game theory*	*optimization*
environmental performance	*energy utilization*	*green supply*	*low-carbon*	*recycling*
inventory management	*environmental impact*	*green logistics*	*product design*	*stochastic models*
transportation	*food supply*	*greenhouse gas emission*	*sustainable operations*	*uncertainty*

A keyword co-occurrence analysis was conducted to identify key themes in SSCM studies related to carbon emissions. Using VOSviewer and the full counting method, this analysis highlights the interrelationships between keywords based on their frequency of occurrence in the literature. A threshold of at least five occurrences was set, resulting in a keyword network divided into five main clusters. Each cluster represents a distinct but interrelated research focus on SSCM and carbon emissions.

The first cluster focuses on supply chain environmental performance and compliance with environmental regulations. The second cluster emphasizes environmentally friendly operational practices, such as green procurement, eco-design, reverse logistics, and process efficiency. The third cluster represents research linking sustainability strategies to company performance, both financial and non-financial. The fourth cluster highlights the role of technology and innovation in supporting carbon emission reduction in the supply chain. The fifth cluster focuses on integrated carbon management in supply chain decision-making. Key themes include integrating carbon emissions into supply chain planning, optimizing logistics decisions, carbon-based supplier selection, and the trade-off between economic and environmental performance.

Based on the results of keyword co-occurrence analysis, cluster one tends to emphasize operational aspects, cluster two discusses renewable energy technologies and life cycle analysis, cluster three focuses on developing countries, cluster four relates to strategic corporate responses to climate change, and cluster five demonstrates market-based policy mechanisms with optimization approaches and uncertainty modeling to systematically achieve emissions efficiency. Figure 3, showing the results of the bibliometric analysis, shows cluster five through the purple network. Cluster five marks a shift in SSCM research from a normative and descriptive approach to a prescriptive and decision-based approach, where policies such as the

Emissions Trading Scheme (ETS) are treated not only as regulatory instruments but also as strategic variables in supply chain design and optimization (Li & Haasis, 2016). The ETS can drive economic efficiency and emissions reductions when integrated into supply chain decision models that consider costs, risks, and demand uncertainty (Wang et al., 2024).

The presence of keywords such as stochastic models and uncertainty in this cluster reflects the academic response to the complexity of global supply chains, which are increasingly influenced by economic volatility, environmental regulations, and sustainability pressures. This approach makes SSCM no longer merely an environmental compliance issue, but rather part of a value-driven supply chain strategy. Furthermore, the presence of keywords such as stochastic models and uncertainty in this cluster demonstrates the academic response to the complexity of global supply chains, which are increasingly vulnerable to economic, policy, and environmental volatility. Ghadge et al. (2020) emphasize that quantitative model-based risk management is crucial in modern SSCM, especially when companies face trade-offs between cost efficiency, environmental sustainability, and supply chain resilience. Cluster 5 was selected for further analysis because it represents the most strategic intersection between technical, policy, and quantitative decision-making approaches to carbon emissions management in sustainable supply chain management (SSCM).

Systematic Literature Review Analysis

Based on the results of the bibliometric analysis and conceptual justification, cluster five became the focus of in-depth analysis due to its ability to represent the integration between supply chain decision-making, carbon policy, and uncertainty management. Of the total number of identified Scopus-indexed studies, the bibliometric clustering process resulted in 71 articles classified into cluster five. Table 4 shows the results of processing the articles in cluster five, which served as input for the SLR analysis using the PRISMA approach, to ensure in-depth analysis was conducted on articles from the most methodologically relevant studies.

Table 4. PRISMA Stages

PRISMA stage	Process	Total Article
Identification	TITLE-ABS-KEY (“sustainable supply chain management” AND “carbon emission”) AND PUBYEAR > 2001 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA, “BUSI”)) AND (LIMIT TO (DOCTYPE, “ar”)).	227
Screening 1	Artikel yang diidentifikasi berada dalam Klaster 5 (*Emissions Trading* & *Optimization*) melalui analisis *co-occurance* Bibliometrik	71
Screening 2	Penyaringan berdasarkan inklusi dan eksklusi yang telah ditentukan dalam penelitian ini	19
Screening 3	Penyaringan berdasarkan pendalaman artikel dengan pendekatan *Outcome* dan *Study Design*	7
Included	Jumlah artikel yang di analisis	7

The presence of keywords such as stochastic models and uncertainty in this cluster reflects the academic response to the complexity of global supply chains, which are increasingly influenced by economic volatility, environmental regulations, and sustainability pressures. The step to ensure that further analysis focuses on the most relevant and impactful studies is using

the PICOS-based PRISMA framework (Page et al., 2021). Of the 71 articles classified into cluster five, a gradual screening and eligibility process was carried out to identify studies that were not only methodologically robust but also rich in managerial and policy implications.

The analyzed articles consist of primary empirical studies employing quantitative methods, ensuring methodological rigor and analytical relevance. To meet the objectives of this review, eligible studies were also required to provide managerial and policy implications related to sustainable supply chain decision-making and carbon emissions management. Of the 19 open-access articles that passed the initial screening stage, the application of rigorous eligibility criteria resulted in seven articles selected for in-depth analysis. These studies constitute the core literature directly addressing the research question, "*How are emission trading mechanisms implemented, and what challenges arise in the practice of sustainable supply chain management within the manufacturing sector?*", both in terms of their methodological approach and substantive contribution to understanding the implementation of emissions trading mechanisms in sustainable supply chain management in the manufacturing sector.Table 5 below presents a summary profile of the seven selected studies, including the methodological approaches used and the focus of key outcomes. It serves as the basis for the thematic synthesis and in-depth qualitative discussion that will be developed in the following subsections

Table 5. Qualitative Data Extraction

No.	Author	Outcome (O)	Study Design (S)
1	Chen et al. (2017)	Identifying the supply chain as a power structure that influences wholesale pricing decisions, retail pricing decisions, and carbon emissions. A balanced power structure (vertical Nash) results in the lowest emissions and best economics compared to unilateral dominance.	*Game Theoretic Approach*
2	Yu & Solvang (2020)	Producing robust facility location decisions by balancing the trade-off between cost-effectiveness and environmental performance (carbon emissions). Network flexibility has been shown to improve decision stability under uncertainty.	*Fuzzy-Stochastic Multi-objective Programming*
3	El Harraki et al. (2024)	Capturing the ripple effect of sourcing decisions. The SINDYc algorithm has been shown to outperform NARX in predictive accuracy for rapid decision-making regarding low-carbon versus high-carbon suppliers.	*Dynamic Model (Prey-Predator)*
4	Sorooshian et al. (2024)	Integrating IoT and Simultaneous Pickup & Delivery (P&D) strategies to simultaneously minimize total costs and carbon emissions in a circular EV battery supply chain network. IoT provides the conditions for a secure and traceable network.	*Bi-objective MILP & AUGMECON*
5	Dohale et al. (2024)	Identifying critical determinants for carbon neutrality. Findings indicate that "Professional Expertise" and "Legal & Certification" are the most influential factors in achieving carbon neutrality, surpassing technical factors.	*MCDM & Machine Learning*

No.	Author	Outcome (O)	Study Design (S)
6	Miranda et al. (2020)	Finds that the most eco-efficient strategy is to minimize the number of simultaneous trips (tours) and stops on electric powered vehicles (ETVs), which directly reduces energy consumption and emissions.	*Hybrid Bi-objective Optimization (HBOO)*
7	Karthick & Uthayakumar (2022)	Proves that logarithmic investments in carbon emission reductions can maximize gross profit despite investment costs, by avoiding severe emissions penalties. The model also handles controllable lead times.	*Fuzzy Inventory Model (VMI-CS)*

Discussion

Traditional static approaches are being abandoned in favor of dynamic models that can handle uncertainty. Static data-based carbon emission management systems are becoming increasingly inadequate in dealing with production fluctuations, demand variability, and dynamic supply chain uncertainty (Arshad et al., 2025). This analysis reveals a paradigm shift from static optimization models to dynamic, data-driven approaches in carbon emission management in the manufacturing sector. Initially, the SSCM concept assumed deterministic parameters and relatively stable system conditions. This study's results indicate that these assumptions are increasingly irrelevant in the context of global supply chains rife with uncertainty.

Yu & Solvang (2020) state that in closed-loop supply chain design, a fuzzy-stochastic multi-objective programming approach is a relevant approach for decision-making. Closed-loop supply chain design will simultaneously reduce the potential for uncertainty in demand, costs, and emissions. The implication is that static models tend to be limited in scope and ignore the ripple effects of strategic decisions, such as sourcing and facility placement, which can spread throughout the supply chain network (Gao et al., 2025). This expands previous understandings, which tended to prioritize cost optimization as the dominant objective, without considering systemic volatility.

Another finding related to the paradigm shift in data-driven emissions trading is found in the research of El Harraki et al. (2024), namely the implementation of data-driven dynamic modeling through a prey–predator approach that is able to capture the ripple effects of sourcing decisions, particularly in the selection of low-carbon versus high-carbon suppliers. The implication is that dynamic models based on NARX, and especially SINDYc, have superior predictive accuracy and control capabilities compared to static approaches, thus supporting faster and more adaptive decision-making (El Harraki et al., 2024).

The paradigm shift is also influenced by the use of digital technologies, such as the implementation of the Internet of Things (IoT) in the circular supply chain for electric vehicle batteries, creating real-time visibility crucial for the simultaneous optimization of costs and emissions (Sorooshian et al., 2024). Furthermore, in research by Arshad et al. (2025), Digital Twin (DT) emerged as a strategic solution to bridge the gap between models and operational reality with a dynamic virtual representation of manufacturing processes, enabling real-time monitoring, continuous simulation, and AI-based carbon emission prediction and optimization. A life cycle assessment (LCA)-based DT framework that integrates simulation tools and a real-time data exchange platform can demonstrate bidirectional data flow between physical and virtual systems, thereby improving the accuracy and relevance of emissions analysis.

In the manufacturing sector, efforts to improve energy efficiency and adopt green technologies often require substantial upfront investment, posing a significant barrier for small and medium-sized enterprises. A key challenge in emissions trading lies in the perceived trade-off between profitability and sustainability. Yu and Solvang (2020) report that a 5.3% reduction in emissions may result in a 3.4% increase in total costs, highlighting the short-term financial burden of green transitions. This challenge is further intensified by evidence that high-emission suppliers incur costs approximately 30% lower than those of low-carbon suppliers, creating a strong economic disincentive for cleaner production (El Harraki et al., 2024).

These challenges are particularly pronounced in energy- and resource-intensive industries, such as the semiconductor sector, where emissions are substantial and the adoption of environmentally friendly production processes requires major technological and operational investments (Kannan et al., 2023). However, the emission–cost trade-off is not necessarily fixed. As shown by Karthick and Uthayakumar (2022), a logarithmic investment strategy in emissions reduction can convert initial cost pressures into competitive advantages by increasing gross profit through the avoidance of high emission penalties.

From a policy perspective, regulatory instruments such as cap-and-trade systems and carbon taxes aim to internalize environmental externalities within firms' production and investment decisions. Although these mechanisms may raise costs in the short term, evidence suggests that, over the medium-to-long term, investments in emission reduction can outweigh the financial risks associated with regulatory penalties and uncertainty (Fisco-Compte et al., 2025). Accordingly, compliance with carbon regulations functions not only as an environmental safeguard but also as a catalyst for long-term efficiency and competitiveness. Consistent with Miranda et al. (2020), studies in automotive manufacturing demonstrate that improvements in energy efficiency, such as reducing vehicle trips and stoppages, can simultaneously lower operational costs, reinforcing the alignment between environmental and economic performance.

Power structures in supply chains influence environmental and economic performance, with a balanced (Vertical Nash) system yielding better environmental and economic performance than a single dominant party, either manufacturing or retail, (Stackelberg game) (Chen et al., 2017). The dominance of one party tends to force high wholesale prices for short-term profits, ultimately sacrificing investment in green technology. The successful implementation of optimization technology is highly dependent on human resources and institutional capabilities. Research by Dohale et al. (2024) in the apparel industry using Bayesian Networks identified that professional expertise and compliance with "laws and certifications" were the most critical determinants in achieving carbon neutrality, surpassing the availability of technology itself. The implication is that the main challenge in Sustainable Supply Chain Management (SSCM) in the manufacturing sector lies not only in the availability of sophisticated optimization models, but also in managerial readiness and a fair collaboration structure among supply chain actors.

Conclusion

The implementation of emissions trading in Sustainable Supply Chain Management (SSCM) in the manufacturing sector, integrating bibliometric approaches and a systematic literature review, demonstrates that the current literature is transitioning beyond static models to a

dynamic, data-driven, and multi-objective approach to address the complexity of carbon decision-making under uncertainty. Manufacturing companies face challenges in implementing emissions trading, as the trade-off between costs and emission reductions is not inherent but is strongly influenced by model design, power structures among supply chain actors, and institutional and policy readiness. By focusing the analysis on the high-emission manufacturing sector, this study clarifies how emissions trading mechanisms can function not only as regulatory instruments but also as drivers of efficiency and long-term competitive advantage. The practical implications of these findings emphasize the importance of integrating carbon policies with optimization technologies and strengthening managerial capabilities. Suggestions for further research include testing the identified models in empirical contexts across countries and industries, and developing dynamic frameworks that simultaneously incorporate policy uncertainty, actor behavior, and technological evolution.

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