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A State-of-the-art Review and Meta-analysis of Quantitative Sustainable Supply Chain Models: Research Implications and Future Perspectives

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In the era of industrialization, implementing successful Sustainable Supply Chain Management (SSCM) in industries has become essential due to limited natural resources and increased pressure from the government and customers. This study reviewed fifty-one peer-reviewed journal articles on sustainability implementation in Indian manufacturing industries following a data-driven approach using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The paper considered quantitative models of the forward supply chain to determine and analyze the critical sustainability implementation drivers and barriers. The first part of the paper elaborates on a state-of-the-art review of the selected topic from 2011 to 2022. Subsequently, a metadata analysis is conducted based on various aspects such as publication year, alignment with Sustainable Development Goals (SDGs), methodological approach, industrial context, and research focus. Thirdly, a step-by-step guideline has been provided to establish a sustainability framework with a practical case implementation. Finally, several future directions have been suggested for improving and extending existing research through methodological advancements and broader industrial applications. The literature study revealed a growing trend in publications, with increasing interest in organizational factors, a dominance of Multi-Criteria Decision-Making (MCDM) tools as research methods, and a comprehensive consideration of all three dimensions of sustainability: economic, social, and environmental.

Keywords: Indian manufacturing, Multi-criteria decision-making, PRISMA, Sustainability framework, Sustainable development goals

Introduction

Over the last two decades, sustainability in Supply Chain Management (SCM) has been a significant focus of research in operations management due to the rapid increase in industrialization. Industries are exploiting natural resources rapidly to conduct their commercial activities and close the demand-supply gap. Therefore, it has become decisive for industries to adopt eco-friendly resource conservation methods and sustainable production in their organizations.[1] The concept of sustainability was first developed by Brundtland in 1987 and adopted by the World Commission on Environment and Development.[2] Sustainability in SCM can be stated as the incorporation of environmental perspective into the traditional SCM of an organization, i.e., achieving the social, economic, and ecological goals for achieving the long-term financial performance of an organization.[1,3] The perception of Sustainable Supply Chain Management (SSCM) has evolved over time, as presented in Table 1.

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For the development of any nation, the manufacturing industry plays a vital role and contributes significantly to the sustainability issue.[9] Since India entered the World Trade Organization (WTO), many manufacturing industries in India have started adopting sustainability in their supply chain.[2] These organizations are facing significant challenges while considering social and economic issues for long-term success, along with the environmental impacts. Therefore, it is essential to identify the factors that affect the adoption of SSCM, considering all three sustainability issues in the Indian manufacturing context.

A considerable number of works have been conducted that reviewed broader aspects of sustainability implementation and provided managerial and conceptual frameworks on these issues. Very few articles have discussed the literature on the barriers and enablers for the application of SSCM in Indian industries, followed by insights into their implementation. This study conducted a systematic review of quantitative supply chain models that have analyzed the factors of SSCM and prioritized them by employing decision analysis tools

Table 1 — The evolution in the SSCM definitions

Year	Definition[Ref]
2008	"SSCM may be defined as the strategic integration and achievement of three dimensions of sustainability (social, environmental, and economic) in the supply chain of an individual firm by improving the long-term economic performance of the same."[4]
2010	"SSCM means the collaboration of producers with the SC members and managing the intra-and inter-organization operations for sustainable development by the organization."[5]
2015	"SSCM works with managing the supply chain policies held, relationships formed, and action is taken to respond to the environmental concerns raised and social issues regarding design, production, distribution, use, and end-of-life management of an organization's goods and services."[6]
2016	"SSCM is a systematic process of managing the social responsibilities of a company along their production processes considering organizational and geographical boundaries."[7]
2017	"SSCM refers to managing raw materials, reducing waste in forward logistics, and managing end-of-life processes in reverse logistics with environmental and social improvement."[8]

like Multi-Criteria Decision-Making (MCDM), statistical methods, etc. The paper will help understand the current scenario of Indian manufacturing industries trying to implement or have already adopted sustainability in their organizations. This study will add some more dimensions to the available works of literature by answering the subsequent research questions:

RQ1: What are the crucial drivers and barriers that accelerate or hinder the adoption of SSCM in Indian manufacturing industries?

RQ2: How can a quantitative SSCM framework be developed to improve organizational sustainability performance?

RQ3: What are the scopes of further exploration in the area of SSCM in the Indian industrial sectors?

A systematic literature review of the relevant literature was conducted to address the research questions. Data have been accumulated, which show the hybrid modelling tools for making a decision analysis system that will help to observe the trend and challenges in adopting sustainability in the upcoming decades.

Methodology

This review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent and consistent selection process.[10] Articles were collected from reliable, peer-reviewed sources to perform a strategic review of SSCM in Indian manufacturing industries. The review process was structured according to the four PRISMA phrases as discussed below and represented using a flow diagram in Fig. 1.

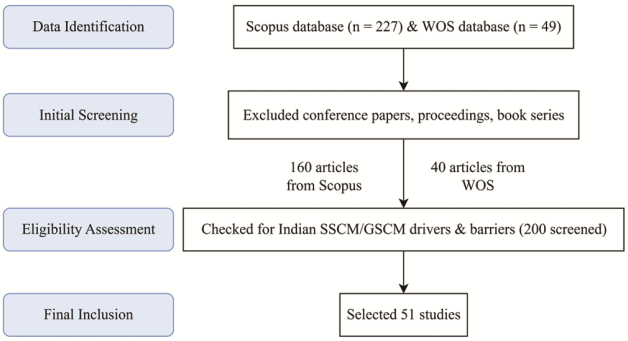

Fig. 1 — PRISMA flow diagram illustrating the stages of data selection methodology

Data Identification

Relevant papers were identified from Scopus and Web of Science (WOS) databases covering publisher platforms such as Taylor and Francis, Elsevier, Emerald, Springer, Wiley, and Inderscience, for 2011–2022. Previously, many researchers have utilized the WOS[11,12] and Scopus[13,14] databases in their studies, which further support the reliability of the data sources used in this review. Key search terms included 'drivers and barriers of sustainable supply chain management', 'green supply chain management', 'SSCM in Indian manufacturing', and 'GSCM in Indian manufacturing'. This initial search yielded 227 documents from Scopus and 49 papers from WOS.

Initial Screening

In the screening phase, conference papers, proceedings, book series, and articles from unreliable journals were excluded. This filtering included 160 articles from Scopus and 40 from WOS for further assessment.

Eligibility Assessment

The remaining 200 articles were then assessed for content relevance, focusing on studies that specifically discussed drivers and barriers of SSCM or GSCM in the Indian manufacturing context.

Final Inclusion

In the final stage, duplicate studies and those not meeting the inclusion criteria were removed. Finally, 51 journal articles were selected for in-depth analysis. This PRISMA-guided approach ensures a systematic

and transparent review process, enhancing the reliability of the synthesized findings.

The reviewed articles expressed a reasonably high methodological rigor and contribution to the research questions. More than 90% of the studies employed MCDM tools as their decision-making strategies, and 20% used a hybrid research methodology to enhance robustness. A further 18% of the studies combined MCDM approaches with statistical validation techniques, providing more reliable and data-driven insights. Furthermore, over 70% of the reviewed studies focused on industry-specific case studies, which offered deep sector-specific insights that contribute strongly to identifying and prioritizing SSCM factors. However, the limited utilization of hybrid research methodology and the lack of extension towards comprehensive SSCM frameworks for cross-sectoral generalizability emphasize the need for more integrated and empirically validated future research.

Metadata Analysis

Statistical analysis is conducted based on the metadata of 51 journal articles to summarize the studies' outcomes and provide a more precise and thorough understanding.

Literature Mapping with UN SDGs

In 2015, all United Nations (UN) members agreed to embrace 17 Sustainable Development Goals (SDGs) that must be accomplished by 2030.[15] Aligning SSCM factors with the UN SDGs helps identify key areas where Indian manufacturing can contribute to sustainability issues, ensuring local practices support broader global goals. The quantitative mapping is provided in Table 2. From the table, it is seen that 47 publications have considered the factors related to SDG 16, indicating that the implementation of sustainability is highly reliant on government regulations, pressure from society, NGOs, and media, and organizational decision-making strategies. Factors dealing with SDG 12 and SDG 17 occurred 42 times in the literature, which signifies that top management commitment, optimization of resources, implementation of reverse logistics, adoption of clean technology, and global marketing are also crucial for SSCM implementation in Indian industries. Also, SDG 8 has been employed by the authors 41 times. Therefore, financial factors, employee stability, and decision-making involvement are crucial for adopting sustainability. As revealed from the analysis, other vital factors of sustainability implementation include environmental education, training, awareness of the public, employees, and suppliers, environmental management certification, and corporate social responsibility.

Articles based on Publication Year

The year-wise search results from the Scopus and WOS databases are summarized in Table 3. The trend

Table 2 — Quantitative mapping of SSCM implementation factors with UN SDGs

UN SDG	No. of studies mapped	% of total (51)
SDG 16 – Peace, justice, and strong institutions	47	15.35
SDG 12 – Responsible consumption and production	42	13.72
SDG 17 – Partnerships for the goals	42	13.72
SDG 8 – Decent work & economic growth	41	13.39
SDG 4 – Quality education	35	11.43
SDG 7 – Affordable & clean energy	31	10.13
SDG 9 – Industry, innovation & infrastructure	27	8.82
SDG 11 – Sustainable cities and communities	27	8.82
SDG 3 – Good health & well-being	14	4.57

Table 3 — Year-wise search results of the number of articles

Publication year	Search terms: Sustainable supply chain management in Indian manufacturing		Green supply chain management in Indian manufacturing		SSCM in Indian manufacturing		GSCM in Indian manufacturing		Total
	Scopus	WOS	Scopus	WOS	Scopus	WOS	Scopus	WOS	
2011	—	1	1	—	—	—	1	—	3
2012	2	—	2	2	—	—	—	—	6
2013	2	4	7	5	1	1	5	4	29
2014	3	5	9	7	1	2	5	2	34
2015	5	3	7	5	2	—	4	3	29
2016	7	6	10	9	—	—	6	1	39
2017	3	10	5	9	—	—	3	1	31
2018	10	22	6	16	3	3	2	—	62
2019	13	22	7	13	3	2	1	—	61
2020	17	22	10	18	5	4	6	2	84
2021	15	28	10	17	2	—	6	—	78
2022	19	40	10	21	3	2	3	2	100

of SSCM-related publications is plotted in Fig. 2. It shows that in 2011, only three articles were published, but the number has gradually increased despite some fluctuations. The graph shows a notable peak in 2022, with the highest number of articles published that year. This upward trend highlights a growing concern and interest in SSCM implementation among industries and practitioners over time. The increasing research focus on SSCM within the Indian context discloses that Indian manufacturing industries are becoming more committed to adopting sustainability. This shift is likely driven by regulatory pressure from the government and increased stakeholder expectations, indicating a significant move towards sustainable practices.

Publication in Top 10 Journals

The top 10 journals, ranked by the number of publications and Impact Factor (IF), are listed in Table 4. The *Journal of Cleaner Production* and *Production Planning & Control* each published six papers, followed by *Resources, Conservation & Recycling* with five. Among these, *Renewable and Sustainable Energy Reviews* has the highest IF, highlighting its influence. The results also indicate a concentration of research in high-impact journals, reflecting the growing academic interest in SSCM.

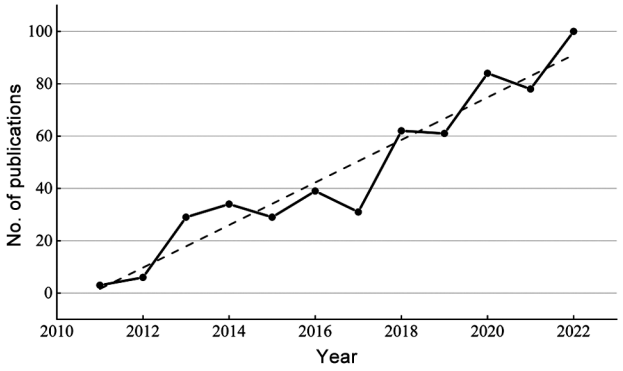

Fig. 2 — Growth trajectory of publications on SSCM by years

Publication by Research Methodology used

The result of the publication by research methodologies shows that 41 papers have used only the MCDM tool as their research methodology.[16–20] MCDM techniques are gaining more attention due to their ability to assess and prioritize the alternatives considering a set of criteria. It can increase the quality of decisions more effectively than traditional methods. MCDM tools are gaining popularity among practitioners and industry managers, depending on their advantages and ability to solve complex problems in various industries.[21] Five papers have used statistical analysis to model their research framework and identify the trends and patterns of unstructured data in a vast data set.[22–26] Five papers have used a combined approach of the MCDM tools and statistical analysis to increase the effectiveness of the problem framework.[27–29] The statistical analysis will help validate the results obtained from MCDM tools and inspect the influential factors.[30] The data classified by the research methodology have been presented with the help of a pie chart in Fig. 3.

Publications According to MCDM Tools

Significant growth has been made in the development of MCDM techniques in the last two

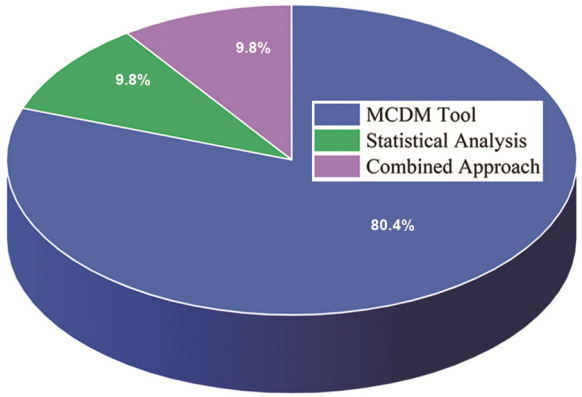

Fig. 3 — Categorization of articles based on research methodology

Table 4 — Top 10 journals, along with publishers and impact factors

Sl. No.	Name of journal	Publisher	No. of Publications	Impact factor (2023)
1	Journal of Cleaner Production	Elsevier	6	9.7
2	Production Planning & Control	Taylor and Francis	6	8.3
3	Resources, Conservation and Recycling	Elsevier	5	11.2
4	Journal of Manufacturing Technology Management	Emerald	4	7.3
5	Sustainable Production and Consumption	Elsevier	3	10.9
6	Resources Policy	Elsevier	2	10.2
7	International Journal of Production Economics	Elsevier	2	9.8
8	International Journal of Production Research	Taylor and Francis	2	9.2
9	International Journal of Sustainable Engineering	Taylor and Francis	2	3.7
10	International Journal of Advanced Manufacturing Technology	Springer	2	2.9

decades. Nowadays, decision-makers use many MCDM tools in different fields of research and industry problems to deal with qualitative and quantitative factors.[31] Out of the 46 articles applying MCDM tools, ISM with MICMAC was used by 16 studies[32–34], followed by hybrid approaches combining two or more methods (nine studies).[35–38] The Analytical Hierarchy Process (AHP) was applied in seven studies[39–41], whereas the Decision Making Trial and Evaluation Laboratory (DEMATEL) was used in five.[42,43] Other tools, such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Total Interpretive Structural Modeling (TISM), Preference Ranking Organization Method for Enrichment Evaluation II (PROMETHEE II), etc., appeared less frequently. A summary of MCDM tool usage is presented in Table 5. More insights on the application of the MCDM tools have been discussed in the subsequent section.

Articles Classification Based on Industrial Sectors

Industries play a critical role in the growth of any country's economy. Large-scale manufacturing industries contribute 20-25% of the Indian Gross Domestic Product (GDP).[44] Research remains incomplete without testing the developed framework. Applying it in a specific industrial sector demonstrates its practical applicability. Fourteen papers have taken general manufacturing industries into their case studies. Based on their views, their generalized outcomes can be applied to any manufacturing industry to develop a sustainability framework. However, these results are not too practical for every sector. Ten articles examined the automobile industry[18,43], where India ranks fourth globally.[45] This highlights the need for sustainability, as developed countries increasingly prefer sustainable suppliers. Another ten papers addressed the mining industry[20,32], a key export sector for India, where adopting sustainable practices is equally crucial. Indian power industries are considered by three articles[46-48], followed by plastic[49], metal[16], textile[2,35], oil and gas[50], cement[22], rubber product[51], heavy equipment, and fastener industry[3], as tabulated in Table 6. As these industries are considered a bit less, there are enormous opportunities to explore the sustainability issues of these sectors.

Articles Related to Different Sustainability Issues

Researchers have considered different sustainability issues when developing implementation frameworks. Their distribution is shown in Fig. 4. It shows that 31 articles considered all three sustainability issues, i.e., social, environmental, and economic. Thirteen papers addressed environmental and economic issues, categorized under green supply chain management. When the social aspect is regarded along with environmental and economic issues, it is only considered sustainable. Recent studies are more

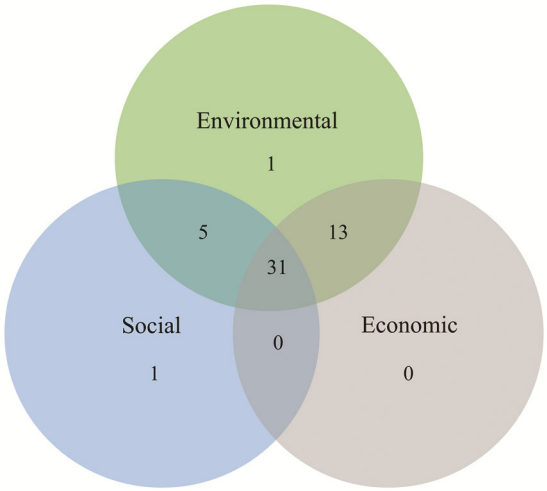

Fig. 4 — Classification of articles according to different sustainability issues

Table 6 — Classification according to industrial sectors in the Indian context

Type of industrial sector	No. of Publications	Percentage (%)
General Manufacturing	14	27.4
Automobile	10	19.6
Mining	10	19.6
Power industry	3	5.9
Plastic	3	5.9
Metal industry	3	5.9
Textile	2	3.9
Oil and gas	2	3.9
Cement	1	2
Rubber product	1	2
Heavy equipment	1	2
Fastener	1	2

Table 5 — Distribution of publications according to MCDM tools and their purposes

MCDM tool	No. of studies	Purpose/advantage
ISM + MICMAC	16	Identifying hierarchical relationships and driving-dependence power
Hybrid methods	9	Combining the strengths of multiple MCDM tools
AHP	7	Simplifying complex problems by ranking criteria
DEMATEL	5	Establishing cause-and-effect relationships
Others	9 (combined)	Various ranking and prioritization approaches

concerned with evaluating social issues along with environmental and economic issues, as industries are mandated to take on social responsibilities.

Leading Authors in Indian SSCM

The top 10 leading authors in the field of SSCM in the Indian context have been tabulated in Table 7. Most authors belong to Indian institutions, and some are from different countries. It indicates that the sustainability implementation of developing countries' manufacturing industries, like India, is getting more attention from foreign authors and foreign institutes, alongside the Indian authors. The co-authorship network is represented in Fig. 5, which reveals that K. Mathiyazhagan, Kannan Govindan, and Kamalakanta Muduli have high publication volumes and strong collaborations.

Articles based on SSCM Implementation Factors

The factors hampering sustainability adoption in a supply chain are called barriers, and those accelerating the adoption are called drivers. Out of 51 papers, 32 studied SSCM drivers, and 29 worked on SSCM barriers. Five studies have considered both. Therefore, it is observed that more papers have considered drivers than barriers in their research, as implementing drivers is relatively easy for industries to adopt rather than removing the barriers. However, considering both will help understand and identify the relationship between drivers and barriers, facilitating more effective management of these factors.

Categorization of the Drivers and Barriers

The factors of sustainability implementation are categorized into two broad categories: internal and external. Internal factors are classified into organizational, technical & engineering, and economic sub-categories. External factors are grouped into four sub-categories: regulatory, environmental, social, and marketing. This categorization was conducted manually through a comprehensive literature review and informed expert judgment. By

Table 7 — Contribution of the top 10 authors in SSCM

Author	Total Publications	Institution (Current), country/region
K. Mathiyazhagan	10	Thiagarajar School of Management, India
Kannan Govindan	9	University of Southern Denmark, Denmark
Kamalakanta Muduli	8	Papua New Guinea University of Technology, Papua New Guinea
A. Noorul Haq	7	National Institute of Technology, Tiruchirappalli, India
Sunil Luthra	6	All India Council for Technical Education, New Delhi, India
Ali Diabat	6	New York University Abu Dhabi, United Arab Emirates
Akhilesh Barve	5	Maulana Azad National Institute of Technology, India
Sachin Kumar Mangla	5	OP Jindal Global University, India & University of Plymouth, United Kingdom
Balkrishna Narkhede	4	National Institute of Industrial Engineering, India
Rakesh D. Raut	4	National Institute of Industrial Engineering, India

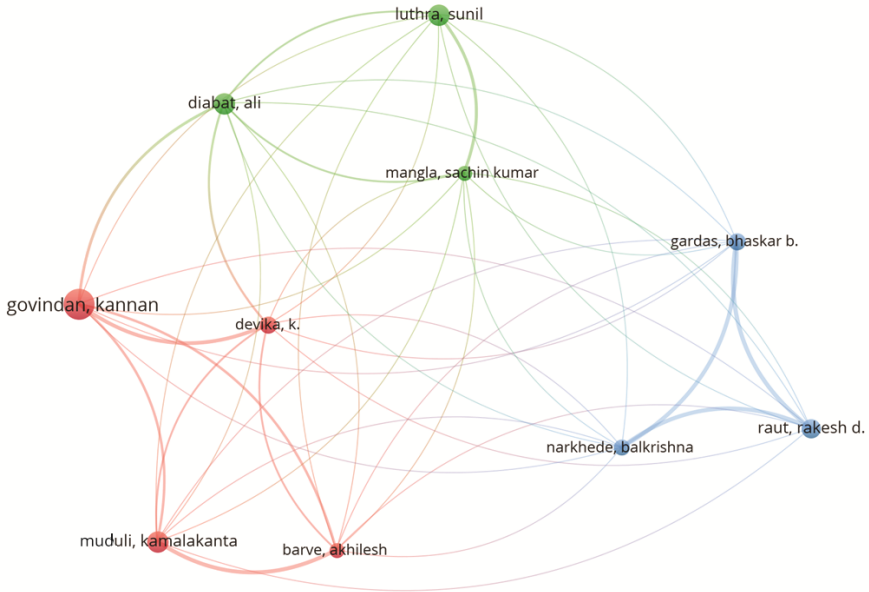

Fig. 5 — Co-authorship network visualization diagram (source: VOSviewer)

analyzing the frequencies of occurrence of the drivers, it is observed that the internal drivers occurred 199 times (53.2%), whereas the external drivers showed a frequency of 175 (46.8%). On the other hand, the internal barriers came out 173 times (73.9%), and the external barriers arose 61 times (26.1%). In both cases, internal factors are considered to have a higher number of occurrences than external ones, indicating that organizational-level elements play a more prominent role in both enabling and hindering the implementation of SSCM. The complete lists of drivers and barriers, with their categories, sub-categories, and the number of occurrences (in brackets), are arranged in Tables 8 and 9, respectively.

Insights of SSCM

Identification and Filtration of Drivers and Barriers

It is essential to choose the implementing factors strategically to adopt successful SSCM practices in an organization. Researchers have identified these factors from a comprehensive literature review and advice of industry managers, manufacturing experts, and academicians for modeling and developing a framework. As many drivers and barriers are available in the industries, dealing with all the implementation factors is difficult. Therefore, it becomes essential to identify and prioritize the most significant obstacles and enablers corresponding to the different manufacturing sectors in India. Consequently, it is crucial to identify the most influential factors, as handling the top-level factors makes it easier to grasp the lower-level factors.[52] Few researchers conducted survey questionnaires[53,54], and some took the help of expert opinion[2,55] to identify the significant factors. Some studies performed factor analysis, a statistical technique to reduce large variables into fewer underlying factors with minimal data loss.[56] Also, some of the researchers took the help of MCDM tools to recognize the most essential Critical Success Factors (CSFs).[22,57]

Choosing the relevant factors for specific industries is crucial because they vary industry-wise depending on their organizational, economic, environmental, and social practices. Therefore, it is suggested to seek experts' advice to select the factors suitable for specific industries instead of a generic selection from the literature review.

Data Validation and Reliability Test

After the final selection of the elements, different studies used different methods to validate and check the reliability of the selected drivers and barriers. Few researchers[36,58] have conducted surveys by preparing a questionnaire and distributing it to suitable industry experts, firm managers, and academicians. One study[27] carried out surveys and interviews with experts in Indian manufacturing industries, and some researchers[1,59] have used Cronbach's alpha test to check the reliability of the factors and the existence of

Table 8 — Categorization of drivers with frequency of occurrences

Category	Subcategory	Sub subcategory	Drivers
Internal (199)	Organizational (119)	Corporate Strategy (32)	Top management commitment (21), Effective strategic planning (6), Lean manufacturing practices (3), Organizational collaboration (2)
		Organizational Culture (24)	Corporate social responsibility (15), SC members' awareness and eco-literacy (5), Potential legal consequences of hazardous waste disposal (4)
		Organizational Resources (46)	Optimizing resource consumption (12), Employee involvement and empowerment (11), Human resources management practices (11), Training of suppliers and employees (9), Other minor drivers (3)
		Organizational Characteristics (17)	Organization's brand image (15), Infrastructure (2)
	Technical & Engineering (55)		Adoption of Green Technology (16), Reverse logistics (12), Green product design and development (11), Implementation of Information Technology (8), Human technical expertise (7), Metrics for sustainability tracking (1)
	Economic (25)		Financial factors (16), Financial incentives (5), Willingness towards investment (3), Investment in R&D (1)
External (175)	Regulatory (56)		Government rules and regulations (28), Environmental management certifications and eco-labelling (19), Tax exemption for EMS-certified firms (4), Other minor drivers (5)
	Social (39)		Customers' awareness (12), Societal pressure (10), Pressure from NGOs and Media (10), Societal concern for protection of the environment (5), Community economic welfare and development (2)
	Environmental (18)		Environmental collaboration with suppliers (7), Total Quality, Environmental Management (3), Environmental collaboration with customers (3), Other minor drivers (5)
	Marketing (62)		Competitiveness (21), Customer requirements and satisfaction (14), Role of stakeholders (11), Roles of suppliers (9), Global marketing (7)

Table 9 — Categorization of barriers with frequency of occurrences

Category	Subcategory	Sub subcategory	Barriers[a]
Internal (173)	Organizational (92)	Corporate Strategy (36)	Higher authority involvement (18), Performance evaluation and reward systems (6), Advanced technology (4), Healthy organizational culture (4), Other minor barriers (4)
		Organizational Culture (36)	Communication and coordination among SC members (8), Corporate social responsibility (7), Awareness of sustainability concepts among SC members (6), Confidence in innovation (4), Clear liability and complication in decision-making (4), Adoption of modern technologies (3), Other minor barriers (4)
		Organizational Resources (20)	Training and development programs about sustainability (8), Authorization at the lower level (3), R&D and innovation potential (3), Skilled workforce (1)
	Technical & Engineering (47)		Expert technicians (13), Technology and processes for facilitating resource optimization (12), Information technology implementation (6), Facility for adoption of reverse logistics (4), Waste management and recycling facilities (3), Simple/reusable product design (3), Other minor barriers (6)
	Economic (34)		Financial support (18), Cost-efficient waste disposal (5), Reliable return on investment (5), Other minor barriers (6)
External (61)	Regulatory (32)		Conducive government regulation (22), Environmental Management Certifications (6), Other minor barriers (4)
	Social (4)		Public pressure (3), Stable political environment (1)
	Environmental (4)		Environmental awareness (4)
	Marketing (21)		Clarity regarding sustainability among customers (10), Customer demand and support (8), Competitiveness (3)

a Unless specified, barriers represent absence or lack of the mentioned factor.

any inconsistency in a set of factors. If an element's value of Cronbach's alpha is higher than 0.6, it is considered acceptable.[59,60]

To ensure data validation, selecting experts with professional backgrounds in SCM and sustainability is crucial, rather than relying on general managers or industrial experts. Therefore, it is suggested that experts be chosen as supply chain managers, chief sustainability officers, ESG (Environmental, Social, and Governance) professionals, and experts in a sustainability-related profession.

Categorizing the Factors

To systematically deal with these factors, it is necessary to categorize them according to the different aspects of sustainability.[22,53] There are three main aspects of sustainability that directly affect sustainability implementation: economic, environmental, and social. Researchers have added more categories like organizational, regulatory, technical, marketing, business-to-business, etc.[1,61,62] Categorizing helps in an overall understanding of the factors and gives an interpretation in which category industries need to focus more, depending upon their influence throughout the supply chain.

Prioritization and Modelling a Framework

Research methodologies need to be applied to prioritize and assess the drivers and barriers. The choice of MCDM tools depends on the research objective and needs of the organizations, like investigating the dominant sustainability factors (value-based Methods: AHP, TOPSIS, etc.), ranking alternatives based on their relative superiority to each other (superiority methods: PROMETHEE, ELECTRE, VIKOR, etc.), understanding causal relationships between the factors (structural and causal analysis methods: ISM, DEMATEL, etc.), or combining complementary strengths via hybrid methods (Table 5).

Some researchers have used statistical methods, like Structural Equation Modeling (SEM), Principal Component Analysis (PCA), regression analysis, ANOVA analysis, t-test, etc. These tools enable data-driven decision-making by providing quantitative validation of the influence of various factors on SSCM and analyzing the trends over time. For modelling and predicting the impact of various SSCM implementation factors, SEM and regression analysis are more suitable for strategic planning and understanding the relationships between them. PCA is valuable in reducing the dataset's complexity and identifying the most influential factors without losing much information. In contrast, ANOVA and t-tests are useful for comparing groups and assessing the effectiveness of sustainability initiatives. Few studies have developed hypotheses, considering the relationships between the factors, to show the impact of one factor on another.[23,24] It helps evaluate the strength of relationships among variables and provides a structured framework for empirical validation and analysis.

Various MCDM tools have been employed to prioritize and structure SSCM factors. Complementarily, statistical methods have been used to reduce complexity and validate causal relationships. A few studies have adopted hybrid approaches, indicating a growing but underexplored potential for integrated methodologies. Future research should systematically appraise such combinations to improve the robustness, credibility, and applicability of SSCM frameworks, strengthening both theoretical and practical contributions.

Validation of the Proposed Framework

Studies of SSCM literature have conducted various real-world case applications applied to different manufacturing industries across India to validate their proposed framework. Researchers have identified and selected companies that need to implement SSCM to improve environmental and social performance and achieve long-term economic business advantages.[63,64]

Many papers have conducted studies on general manufacturing industries, i.e., collecting data from various manufacturing industries and applying it to their research framework, claiming that the outcomes will be helpful for all types of manufacturing industries. However, collecting data from specific manufacturing industries is recommended for more accurate outcomes and a more precise evaluation of SSCM factors. Data from similar sectors across different regions of a country can further improve precision.

Some researchers have accomplished a sensitivity analysis to check the consistency of the experts' decisions.[28,65] Sensitivity analysis is conducted to observe the effect of changes in the rankings.[37] If it affects the hierarchy of the other factors substantially, then the chosen element is considered significant. If the selected characteristic is a barrier, removing it will make it easier to eliminate the remaining obstacles. One of the study[66] validated their developed model statistically using SEM to measure and analyze the causal relationship between parameters. Also, it can test the data to fit the proposed framework and detect any inconsistencies in human judgments.[67]

Implications for Designing the SSCM Network

A comprehensive review of the available literature and insights into SSCM adoption in Indian manufacturing industries has been provided to help frame a Sustainable Supply Chain (SSC). This section presents a practical guideline for developing an SSC network based on the analysis of the reviews, which will help researchers, academicians, industry managers, and policy-makers design their own SSC network.[29]

A flow chart in Fig. 6 represents designing an SSCM network. Before initiating the network design, it is crucial to analyze the fundamental requirements. Financial needs are the first prerequisite to initiate sustainability, as investors are willing to invest in sustainable infrastructure.[68] Indian manufacturers need Foreign Direct Investment (FDI) to demonstrate their commitment to sustainability and attract stakeholders. The following important factor is government rules and regulations, which should favour the firms interested in implementing sustainability in their supply chain.[57] Another key consideration is customer requirements, as products and services must align with evolving consumer expectations for sustainable practices.[29] Finally, organizations need to engage employees with adequate technical knowledge and expertise to enable the smooth adoption of SSCM practices.

Once these requirements are addressed, the next phase is to recognize the sustainability factors of manufacturing industries. This stage is primarily executed through literature reviews and input from industry experts and academicians. Since not all gathered data is suitable for applying research

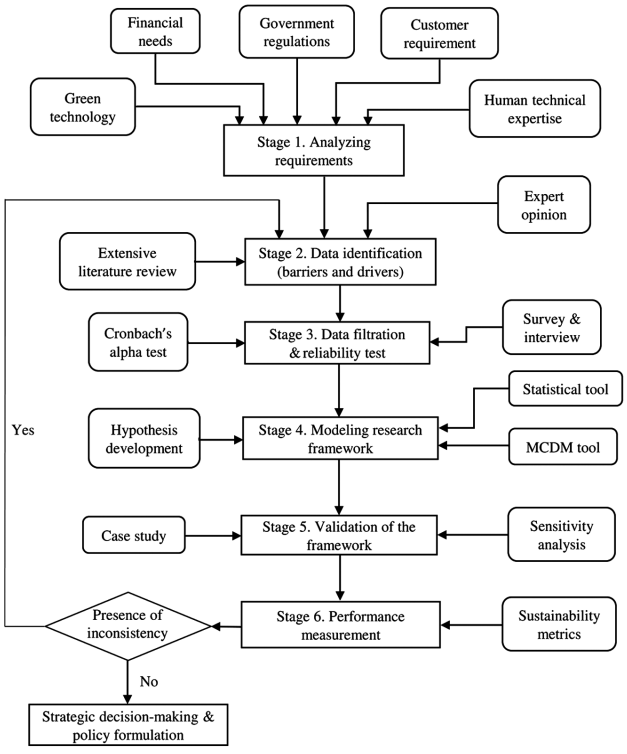

Fig. 6 — The designing process of an SSCM network (Modified from Masoumi *et al.*[14])

methodology, it is necessary to filter the data and verify the reliability of the selected factors. Methods like Cronbach's alpha test can be used for reliability checks.

After finalizing the relevant SSCM factors, the SSC framework can be modelled using decision-making techniques such as MCDM tools and statistical methods to evaluate and prioritize them. The framework can then be validated by applying it to a real-world industrial case and validating the results through a sensitivity analysis.

To demonstrate practical applicability, the designed framework was tested using inputs from three experts from a steel manufacturing industry seeking to adopt sustainability in its supply chain in eastern India. Initially, 10 drivers were selected from a literature study and experts' opinions. Then, Cronbach's alpha test is carried out to finalize the drivers into eight numbers. Data were collected using a structural self-interaction matrix, which was then evaluated using the fuzzy DEMATEL technique to recognize cause-and-effect relationships and prioritize crucial drivers. The analysis revealed that financial factors and green manufacturing are primary drivers for SSCM adoption in the Indian steel industry. In contrast, adoption of green technology and green product design and development were found to be more dependent outcomes, influenced by these key drivers. These outcomes allow industries to make strategic decisions and formulate sector-specific policies. After adopting the strategies, performance can be tracked using sustainability metrics, with feedback from managers guiding corrective actions for sustainable value creation. The case application results (Table 10) validate the framework's ability to model interdependencies among SSCM factors and provide actionable insights for decision-makers.

Recommendation for Future Research

Despite growing research in sustainability in Indian manufacturing sectors, few areas are inspected to a lesser extent. The implications below might further benefit future researchers and practitioners in this area.

Sector-Specific Focus on High-Impact Industries

Indian manufacturing sectors seek sustainability to strengthen operational efficiency with minimal environmental impact. Among all industries, the Indian steel sector alone contributes 55% of the environmental impact.[9] Yet, it remains underexplored in existing literature. The growth of other manufacturing industries will help the iron and steel industry grow due to increased steel consumption, amplifying its sustainability challenges. Future research should employ more implementation-oriented frameworks, such as sector-specific sustainability roadmaps and policy-linked modelling approaches, to guide practitioners in overcoming unique challenges in high-impact industries like steel.

Hybridization of Decision-Making Techniques

Previous studies have shown that MCDM techniques are far better than intuitive evaluation and ranking applications in different companies.[68] However, each of these MCDM tools has its own limitations. Very few practitioners have used hybrid MCDM tools or combined approaches. Therefore, it is necessary to perceive the drawbacks of a single method and combine it with other MCDM tools. Combinations like TISM-DEMATEL, ANP-DEMATEL, ANP-VIKOR, AHP-DEMATEL, or AHP-TOPSIS have been used selectively but not comprehensively in sustainability research.[69,70] Also, more than two MCDM tools can be integrated to improve the precision and visualization of a complex problem, refining the methodological combinations to enhance accuracy and interpretability.

Integration of Statistical and Optimization Models

MCDM tools alone cannot fully capture complex interdependencies among SSCM factors. Future research should integrate MCDM tools with statistical

Table 10 — Importance score and classification of the drivers under the case study

Driver	D (Influence)	R (Dependence)	D + R	D – R	Classification	Weight	Relative weight	Rank
Government rules and regulations	3.470	2.344	5.814	1.126	Cause	5.922	0.092	8
Adoption of green technology	3.240	5.071	8.311	−1.830	Effect	8.511	0.132	4
Competitiveness	4.219	3.938	8.158	0.281	Cause	8.162	0.127	5
Top management commitment	4.222	4.414	8.636	−0.192	Effect	8.638	0.134	3
Financial factors	4.915	3.699	8.613	1.216	Cause	8.699	0.135	1
Green product design and development	3.690	4.240	7.930	−0.550	Effect	7.949	0.124	6
Implementation of information technology	3.742	3.988	7.730	−0.246	Effect	7.734	0.120	7
Green manufacturing	4.429	4.234	8.663	0.195	Cause	8.665	0.135	2

validation methods such as SEM, PCA, regression analysis, expectation test, correlation analysis, or network analysis to yield more valid and reliable results. Using multivariate techniques, SEM statistically validates the proposed model and fits the selected data. Correlation analysis identifies the strength and direction of relationships between SSCM factors, supporting better prioritization. On the other hand, network analysis reveals the interdependencies and influence pathways among factors, providing a holistic understanding of their interactions. As there may be ambiguity in experts' judgments while applying MCDM techniques, SEM and correlation analysis serve as complementary validation tools. Also, implementing Operations Research (OR) tools (like linear programming, goal programming, data envelopment analysis, etc.) with the combination of MCDM tools can improve inequitable outcomes.

Developing Implementable Strategies for Overcoming Barriers

Most papers have identified sustainability drivers and barriers, but fail to propose practical strategies for overcoming these hurdles. Since most barriers are closely linked with specific drivers, future work should establish mathematical or simulation-based models that map these relationships and convert them into decision-support strategies. These strategies will allow managers to prioritize interventions and track the impact of removing critical barriers, accelerating sustainability implementation in real-world supply chains.

Operationalizing Sustainability Performance Metrics

To determine the sustainability progress of industries, it is necessary to track their performance using sustainability metrics. Limited research addresses Key Performance Indicators (KPIs) or life cycle sustainability assessment, such as carbon footprint, energy consumption, waste recycling rate, supply chain miles, or sustainability indices, to assist in tracking sustainability progress.[71,72] Future studies should design sector-specific sustainability metrics, along with frameworks for integrating these KPIs into managerial dashboards.

Cross-Sectoral Comparative Studies

Most of the researchers have conducted case studies over a single industrial sector. The outcomes of these studies show that the results of various industries are different. However, there are no studies that compare the results of inter-sectoral outcomes. Therefore, there is a need to investigate insights into this discrepancy by employing comparative multi-sectoral analyses, using both quantitative (e.g., cluster analysis, network analysis) and qualitative (e.g., grounded theory) approaches to reveal why sustainability adoption patterns differ.

Integrating Forward and Reverse Logistics in SSCM Frameworks

Reverse logistics reduces an organization's environmental impact by minimizing inventory carrying costs, transportation costs, carbon footprint, and waste disposal problems. Limited studies have been found that have integrated forward and reverse logistics for developing the SSCM implementation framework. Therefore, there is enormous potential to establish integrated SSCM frameworks that combine forward and reverse flows, supported by simulation models or digital twins, to optimize overall supply chain sustainability, providing more realistic, implementation-ready solutions for organizations.

Conclusions

As a developing country, India's manufacturing sectors need special attention, given their significant contribution to its growth and development. India has the potential to become a global manufacturing hub by 2030, which is driven by factors such as a skilled workforce, a vast customer base, low operating costs, and strong connections to key international markets, attracting more investors. However, investors will consider all aspects of sustainability before investing, forcing Indian manufacturing sectors to adopt sustainability without further delay. A quantitative literature review has been performed on the forward supply chain of Indian manufacturing industries, offering valuable insights for practitioners addressing key elements of SSCM execution. Furthermore, a structural outline is presented to guide the development of a framework for practical SSCM implementation with a case study. Since this study is carried out in the Indian context, the critical elements of sustainability implementation may vary in other developing countries due to differences in geographical locations or political views. Additionally, investigating sustainability implementation factors in developed countries could provide insights into how these factors might be applied to supply chains in developing countries.

Conflict of interest

The authors declare that they have no known conflict of interest for this reported work.

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