# UNCOVERING THE INTERACTIONS AMONG BARRIERS TO SUSTAINABLE SUPPLY CHAIN MANAGEMENT: INSIGHTS FROM KERALA'S LEADING TEXTILE MANUFACTURING INDUSTRIES

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This study explores barriers to Sustainable Supply Chain Management (SSCM) in Kerala's textile manufacturing sector using the ISM-MICMAC approach. It identifies and analyzes ten key barriers: lack of clear policies, financial constraints, poor supplier performance, inadequate infrastructure, high implementation costs, insufficient training, low stakeholder commitment, regulatory challenges, technological limitations, and unfavorable supplier attitudes. Among these, "lack of clear policies and practices" emerges as the most influential root-cause barrier, driving systemic inefficiencies. The findings offer a structured framework for policymakers and industry stakeholders to develop effective SSCM strategies, enhancing operational efficiency and fostering a more sustainable and resilient textile supply chain.

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## 1 Introduction

The textile and apparel industries are vital to the global economy, contributing to employment, trade, and technological advancement. In India, this sector accounts for 2% of the GDP and 12% of export revenue, employing approximately 45 million people across organized and unorganized segments. In Kerala, it plays a key role in regional development and job creation. However, the textile industry is the world's second-largest polluter, generating greenhouse gas emissions, toxic wastewater, and excessive waste, highlighting the urgent need for Sustainable Supply Chain Management (SSCM) practices.

SSCM aims to reduce environmental impact while enhancing social and economic performance. Despite significant investments in quality and innovation, Kerala's textile manufacturers face barriers to SSCM adoption, including poor stakeholder communication, limited awareness of green practices, reliance on conventional technologies, inadequate reverse logistics, and insufficient infrastructure. These challenges hinder alignment with global sustainability standards and the transition to a circular economy.

While existing research identifies barriers like communication gaps, lack of advanced technology, inadequate training, and poor waste management through methodologies such as Interpretive Structural Modelling (ISM), MICMAC, and DEMATEL, most studies focus on macro-level insights in industrialized regions. There is limited research on how these barriers interconnect in Kerala's smaller-scale, labor-intensive textile sector.

This study identifies key barriers to Sustainable Supply Chain Management (SSCM) in Kerala's textile manufacturing industry, offering actionable insights to foster sustainable practices. Given Kerala's commitment to environmental preservation, it addresses the region's unique infrastructural and systemic challenges. Using the ISM methodology, it identifies, and categorizes the barriers while mapping their interdependencies.

For manufacturers, the study provides a framework to prioritize barriers, aiding resource allocation and decision-making. Policymakers can use these insights to design targeted interventions like capacity-building initiatives and infrastructure improvements. Addressing challenges such as communication gaps, outdated technologies, and limited reverse logistics can enhance the region's sustainable supply chain ecosystem. Academically, the study contributes to SSCM literature through a region-specific case study bridging theory with practice. Using Interpretive Structural Modelling (ISM), it analyzes interdependencies among barriers, offering insights applicable to both academic research and industry.

The findings contribute region-specific insights to the SSCM literature and offer practical recommendations for industry leaders, policymakers, and stakeholders. This research aims to guide Kerala's textile firms in adopting sustainable practices, improving competitiveness, and reducing environmental impact. By analyzing SSCM barriers and their interdependencies, the study provides a clear roadmap for transforming Kerala's textile industry into a more sustainable and responsible sector.

## 2 Literature review

The integration of Artificial Intelligence (AI) in the textile industry is driving significant advancements in manufacturing, design, quality control, and sustainability (Kumar et al., 2024). In India, AI adoption has led to improved manufacturing efficiency, increased worker productivity, and reduced product development lead times (Reenu et al., 2024). Moreover, AI plays a crucial role in enhancing Environmental, Social, and Governance (ESG) reporting for organizations, particularly Micro, Small, and Medium Enterprises (MSMEs) in India (Kulkarni et al., 2023). These developments collectively contribute to the evolution of sustainable supply chain management (SSCM) by promoting resource optimization, minimizing environmental impact, ensuring compliance with ESG standards, and fostering transparency and traceability across the value chain. By embedding AI into supply chain processes, the textile industry is better equipped to align with global sustainability goals and build more resilient, responsible supply networks.

Sustainable supply chain management (SSCM) integrates social and environmental considerations into conventional supply chain management, extending its focus beyond economic aspects (Seuring & Müller, 2008). Key drivers for SSCM adoption include consumer demand for ethically sourced products, growing environmental awareness, and regulatory pressures, particularly in resource-intensive industries like textiles (Carter & Rogers, 2008). SSCM aims to reduce the environmental and social impacts of supply chains through green technologies, waste reduction, ethical labor practices, and sustainable procurement (Ahi & Searcy, 2013). The textile industry, known for its significant carbon footprint, water consumption, and chemical waste, produces over 1.2 billion tonnes of CO2 equivalent annually (Allwood et al., 2006). Sustainable practices in this sector are crucial for legal compliance, enhancing corporate social responsibility (CSR) profiles, reducing environmental impact, and improving long-term competitiveness.

Implementing SSCM strategies in the textile sector faces substantial challenges, primarily financial constraints. Investments in green technologies and sustainable raw materials are capital-intensive, particularly for small and medium-sized enterprises (SMEs), which dominate textile manufacturing (Harris et al., 2002). Many firms, especially in developing countries, struggle to secure funding for initiatives with delayed financial returns (Seuring & Müller, 2008). High upfront costs discourage long-term investments in sustainable technologies (Gunasekaran et al., 2015). Additionally, disposing of hazardous waste incurs significant expenses, particularly in textile finishing and dyeing processes (Srivastava, 2007). The lack of recycling facilities and high environmental compliance costs further burden firms (Govindan et al., 2015). Textile industries in regions like Kerala face difficulties meeting stringent environmental standards due to the high costs of waste management.

Infrastructure deficiencies further impede SSCM implementation. Limited recycling and waste disposal infrastructure restrict sustainable supply chain practices (Sarkis et al., 2011). Kerala's textile industry, for instance, requires advanced recycling facilities to adopt a circular economy model. Inadequate infrastructure hampers effective waste treatment, resulting in resource inefficiencies and environmental harm. Moreover, the limited market for recycled materials poses additional challenges. Textile companies struggle to find buyers for recovered materials, discouraging investment in recycling initiatives (Govindan et al., 2015). A lack of skilled personnel and training on sustainable practices exacerbates these issues, as businesses face difficulties implementing and managing sustainability initiatives (Ageron et al., 2012). Insufficient internal and external support within supply chains further limits SSCM adoption (Kumar & Saini, 2017).

Various barriers to SSCM implementation identified in the literature were explored and are presented in the table below.

**Table 1: Barriers in SSCM implementation**

| Sl. No | Barrier name | Description | Reference |
|---|---|---|---|
| 1 | Lack of government initiatives | Lack of support and commitment from top management limits SSCM initiatives. | Tayet al. (2015), Govindan et al. (2014), Luthra et al. (2011) |
| 2 | Poor organizational structure | Inefficient organizational structure hinders smooth implementation of SSCM. | Mathiyazhagan et al. (2013), Muduli et al. (2013), Luthra et al. (2011) |
| 3 | Lack of commitment by top level management | Lack of support and commitment from top management limits SSCM initiatives. | Tayet al. (2015), Govindan et al. (2014), Muduli et al. (2013) |
| 4 | High initial cost of implementation | Significant initial investment required for SSCM implementation can be a deterrent. | Govindan et al. (2014), Zhu and Geng (2013), Mathiyazhagan et al. (2013), |
| 5 | Lack of policies and practices for the retention of skilled and experienced employees in the organization | Difficulty in retaining skilled and experienced employees hampers SSCM implementation. | Mathiyazhagan et al. (2013), Muduli et al. (2013) |
| 6 | Lack of proper rewards and acceptance from the government | Inadequate government support and incentives can discourage SSCM adoption. | Mathiyazhagan et al. (2013), Luthra et al. (2011), Faisal (2010) |
| 7 | Lack of knowledge and training in SSCM | Insufficient knowledge and training among employees can hinder effective SSCM implementation. | Govindan et al. (2014), Mathiyazhagan et al. (2013) |
| 8 | Lack of monitoring and control | Absence of proper monitoring and control mechanisms can lead to deviations from SSCM goals. | Govindan et al. (2014), Zhu and Geng (2013), Muduli et al. (2013) |
| 9 | Fear of failure | Fear of failure can discourage organizations from taking risks and adopting innovative SSCM practices. | Govindan et al. (2014), JMTM 30,6 Mathiyazhagan et al. (2013), |
| 10 | Lack of clear policies and practices | Ambiguous policies and practices can hinder effective SSCM implementation. | Muduli et al. (2013), Ravi and Shankar (2005) |
| 11 | Lack of budget for SSCM implementation | Insufficient budget allocation can limit the scope and effectiveness of SSCM initiatives. | Govindan et al. (2014), Faisal (2010) |

| Sl. No | Barrier name | Description | Reference |
|---|---|---|---|
| 12 | Inconsistent and inadequate performance measures | Lack of clear and consistent performance measures can hinder evaluation and improvement of SSCM practices. | Tayet al. (2015), Govindan et al. (2014) |
| 13 | Complexity of design to reuse/recycle the used products | Complex product design can increase the cost and difficulty of recycling and reuse. | Govindan et al. (2014), Mathiyazhagan et al. (2013) Bhanot et al. (2015), Luthra et al. (2015) |
| 14 | Lack of benchmark in India | Absence of industry benchmarks can make it challenging to measure and improve SSCM performance. | Zhu and Geng (2013), Faisal (2010), Ravi and Shankar (2005) |
| 15 | Lack of supply chain support | Lack of cooperation and support from supply chain partners can hinder the implementation of sustainable practices. | Faisal (2010), Ravi and Shankar (2005) |
| 16 | Lack of markets for recycled materials | Limited demand for recycled materials can discourage recycling efforts. | Govindan et al. (2014), Faisal (2010) |
| 17 | Lack of infrastructure facilities for SSCM implementation | Lack of adequate infrastructure can hinder the implementation of SSCM initiatives. | Govindan et al. (2014), Muduli et al. (2013) |
| 18 | Lack of motivation in adopting SSCM | Lack of motivation and awareness among employees can hinder the adoption of SSCM practices. | Muduli et al. (2013), Faisal (2010) |
| 19 | Lack of strategic planning | Absence of a clear strategic plan can limit the effectiveness of SSCM initiatives. | Mathiyazhagan et al. (2013), Muduli et al. (2013), Luthra et al. (2011), |
| 20 | Lack of experts in providing expert opinion about sustainable practices | Difficulty in accessing expert advice can hinder the implementation of sustainable practices | Govindan et al. (2014), Mathiyazhagan et al. (2013) |
| 21 | Negative attitude of suppliers toward supplying sustainable raw materials | Resistance from suppliers to supply sustainable materials can limit the adoption of sustainable sourcing practices. | Mathiyazhagan et al. (2013), Zhu and Geng (2013), Faisal (2010) |
| 22 | Lack of mutual trust among the supply chain members | Lack of trust among supply chain partners can hinder collaboration and information sharing. | Tayet al. (2015), Govindan et al. (2014), Luthra et al. (2011) |
| 23 | Lack of supply chain partners' performance | Poor performance of supply chain partners can negatively impact the overall | Bhanot et al. (2015), Govindan et al. (2014), |

| Sl. No | Barrier name | Description | Reference |
|---|---|---|---|
| | | sustainability performance of the organization. | Mathiyazhagan et al. (2013) |
| 24 | High cost of hazardous waste disposal | High disposal costs can discourage the adoption of sustainable waste management practices. | Govindan et al. (2014), Mathiyazhagan et al. (2013) |
| 25 | Lack of new technology, materials and processes | Limited availability of new technologies and materials can hinder the development of sustainable solutions. | Muduli et al. (2013) |
| 26 | Resistance to change due to fear of unemployment | Fear of job loss can lead to resistance to change and hinder the adoption of new sustainable practices. | Tayet al. (2015), Govindan et al. (2014), Luthra et al. (2011) |
| 27 | Distraction or slowdown due to existing projects | Ongoing projects can divert resources and attention away from SSCM initiatives. | Faisal (2010), Ravi and Shankar (2005) |
| 28 | Unclear understanding of economic benefit | Lack of clarity regarding the economic benefits of SSCM can discourage investment in sustainable practices. | Muduli et al. (2013), Ravi and Shankar (2005) |
| 29 | Frequent changes in managerial body | Frequent changes in management can disrupt the continuity of SSCM initiatives. | Muduli et al. (2013), Ravi and Shankar (2005) |

Methodologies such as Interpretive Structural Modelling (ISM) and MICMAC analysis are valuable for understanding and addressing SSCM challenges. ISM, developed by Warfield (1974), identifies relationships between system components and arranges them hierarchically based on their interdependencies. This method is effective for analyzing SSCM barriers, revealing how financial constraints and implementation costs cascade into other issues like supplier collaboration and infrastructure deficits (Ahi & Searcy, 2013). MICMAC analysis (Cross-impact matrix multiplication applied to classification) complements ISM by mapping driving and dependent barriers, clarifying their mutual influence (Saaty, 2005). For instance, inadequate recycling infrastructure may depend on government policies and financial support. These methodologies enable firms to prioritize interventions that address multiple barriers simultaneously, enhancing SSCM effectiveness (Seuring & Müller, 2008; Bai & Sarkis, 2014).

Kerala's textile sector faces unique SSCM challenges, including regulatory gaps and supplier resistance. Unlike regions with well-defined sustainability mandates and incentives, Kerala lacks a robust regulatory framework, creating uncertainty and discouraging investment in sustainable practices (Govindan et al., 2015). Supplier reluctance to provide sustainable raw materials is another critical issue. Many textile manufacturers struggle to find reliable, cost-effective sources of sustainable materials due to low demand and concerns about increased production costs (Kumar & Saini, 2017). Small local suppliers, lacking resources to adopt sustainable processes, further compound this problem. Despite these challenges, some textile firms in Kerala have implemented waste reduction measures and prioritized eco-friendly raw materials, aligning with global sustainability trends. However, persistent financial and infrastructural barriers continue to hinder broader adoption.

Tools like ISM and MICMAC provide a structured approach to identifying and prioritizing SSCM barriers in the textile industry. By mapping interdependencies and addressing primary obstacles, firms can enhance supply chain sustainability and competitiveness. Successful SSCM adoption requires comprehensive strategies involving financial investment, infrastructure development, and collaborative efforts across the supply chain.

## 3 Methodology

This study adopts a mixed-methods approach to examine barriers to sustainable supply chain management (SSCM) in Kerala's textile manufacturing industry. Semi-structured interviews were conducted with five supply chain managers from different textile manufacturing firms, and secondary data was gathered through a literature review. Data analysis involved identifying barriers, developing a Structural Self-Interaction Matrix (SSIM), and applying Interpretive Structural Modelling (ISM) and MICMAC analysis to explore barrier interconnections, root causes, and key drivers affecting SSCM adoption. An Overview of research methodology is presented in figure 1.


**Figure 1: Overview of research methodology**

### Step 1: Identification of Barriers

The research began with a comprehensive literature review to identify potential barriers to sustainable supply chain management (SSCM) in Kerala's textile manufacturing industry. This involved analyzing previous research papers, publications, and reports to identify common challenges within related academic domains. Through this process, a preliminary list of 29 potential barriers was compiled as presented in table 1.

### Step 2: Barrier Shortlisting

The initial list of 29 barriers was refined through expert consultation. Semi-structured interviews were conducted with five supply chain managers from various textile manufacturing firms to gather insights on the most critical barriers. This process resulted in a shortlist of 10 key barriers for further analysis. The 10 key barriers are presented below.

B1: High initial cost of implementation
B2: Lack of knowledge and training in SSCM
B3: Lack of budget for SSCM implementation
B4: Lack of infrastructure facilities for SSCM implementation
B5: Lack of supply chain support

B6: Lack of markets for recycled materials
B7: Lack of clear policies and practices
B8: Negative attitude of suppliers toward supplying sustainable raw materials
B9: Lack of supply chain partners' performance
B10: High cost of hazardous waste disposal

**Step 3: Structure in Hierarchy**

The 10 shortlisted barriers were organized hierarchically using the Interpretive Structural Modelling (ISM) technique. This method helped map the relationships and interdependencies among the barriers, providing a clear visualization of how they influence one another. The ISM framework highlighted the most influential barriers and their root causes, offering a structured understanding of the problem. The various stages of ISM and MICMAC approach is presented in figure 2.

**Step 4: Barrier Classification**

The Matrix of Cross-Impact Multiplications Applied to Classification (MICMAC) analysis was employed to categorize the barriers based on their driving and dependence power. Each barrier was classified into one of four categories:

- **Independent Barriers:** High driving power and low dependence power.
- **Dependent Barriers:** High dependence power and low driving power.
- **Linkage Barriers:** Moderate driving and dependence power, indicating mutual influence.
- **Autonomous Barriers:** Low driving and dependence power, having minimal influence.

This classification provided deeper insights into the dynamic relationships between barriers and their influence on SSCM practices.

**Interpretive structural model**

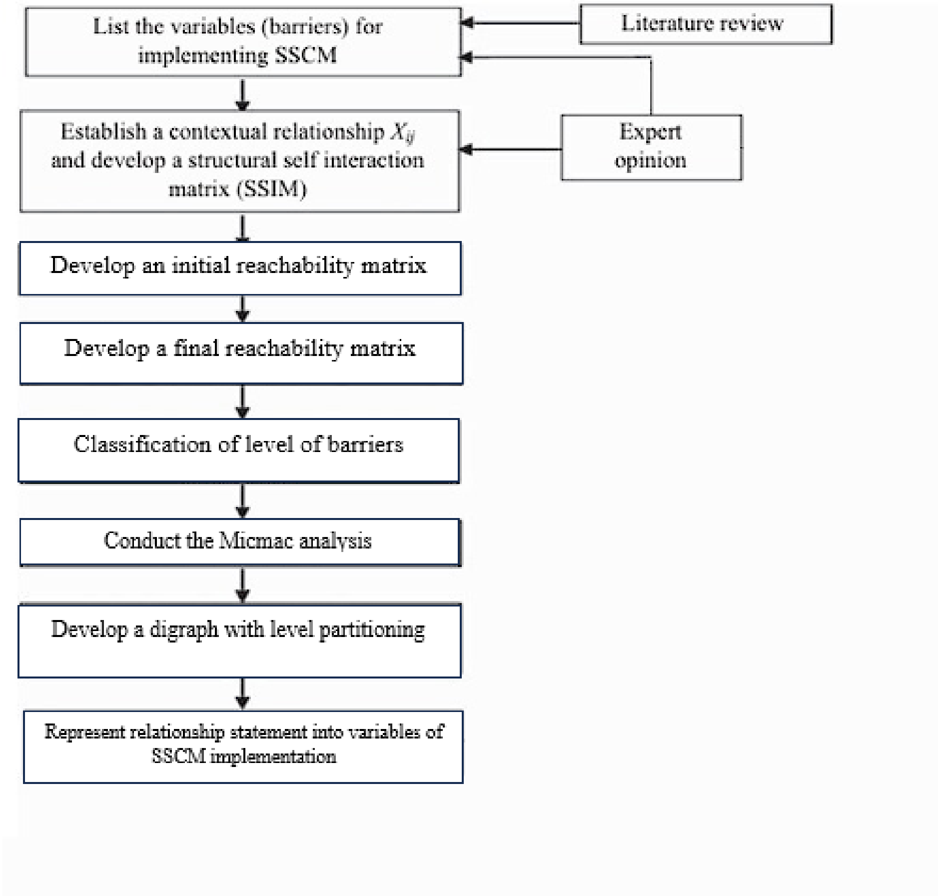


**Figure 2: Stages of ISM MICMAC Approach**

With reference to the textile manufacturing sector under investigation, this research study aims to identify and analyze the barriers to Sustainable Supply Chain Management (SSCM) implementation in Kerala's textile industry. Addressing these challenges is crucial for fostering sustainable practices within the region's supply networks. The research employs the Interpretive Structural Modeling (ISM) methodology to develop a structured framework for categorizing and ranking the primary obstacles to information exchange. This framework provides decision-makers with a systematic approach to address these barriers and lays the foundation for achieving long-term sustainable growth in the supply chain.

This kind of problem formulation is particularly well-suited for the ISM approach, which relies on expert opinions to analyze complex relationships. For this study, opinions were gathered from five specialists, each possessing extensive knowledge and expertise in SSCM and the textile industry. Their insights play a critical role in identifying and analyzing the interdependencies among barriers. The relationships between these barriers are depicted using the "i" and "j" notation to indicate directionality and influence.

A Structural Self-Interaction Matrix (SSIM) of order 10 × 10 was constructed based on the contextual relationships between the identified barriers. This matrix was populated using the expert panel's evaluations, with each symbol reflecting the direct relationship between barriers. The symbols used in the SSIM are defined as follows:

**The relationships between the barriers are represented using the following symbols:**

- **V** = Barrier 'i' influences barrier 'j'.
- **A** = Barrier 'j' influences barrier 'i'.
- **X** = Barrier 'i' and 'j' influence each other.
- **O** = Barrier 'i' and 'j' are unrelated.

**The identified barriers and their corresponding codes are as follows:**

- **B1:** High initial cost of implementation
- **B2:** Lack of knowledge and training in SSCM
- **B3:** Lack of budget for SSCM implementation
- **B4:** Lack of infrastructure facilities for SSCM implementation
- **B5:** Lack of supply chain support
- **B6:** Limited markets for recycled materials
- **B7:** Absence of clear policies and practices
- **B8:** Negative attitude of suppliers toward providing sustainable raw materials

- **B9:** Inadequate performance of supply chain partners
- **B10:** High cost of hazardous waste disposal

### Structural Self-Interaction Matrix (SSIM)

The Structural Self-Interaction Matrix (SSIM) evaluates the relationships among ten key obstacles to implementing Sustainable Supply Chain Management (SSCM). Using symbols such as V, A, X, and O, the matrix illustrates how each barrier influences or interacts with others. This analytical tool helps identify the primary barriers and their interdependencies, providing a foundation for further investigation.

**Table 2: Structural self-interaction matrix**

**Structural Self-Interaction Matrix (SSIM)**

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| High initial cost of implementation | | A | O | A | A | O | A | V | A | O |
| Lack of knowledge and training in SSCM | | | A | V | V | V | A | V | V | V |
| Lack of budget for SSCM implementation | | | | V | V | V | A | O | V | O |
| Lack of infrastructure facilities for SSCM implementation | | | | | V | A | A | V | V | V |
| Lack of supply chain support | | | | | | A | A | A | V | V |
| Lack of markets for recycled materials | | | | | | | A | A | A | O |
| Lack of clear policies and practices | | | | | | | | V | V | V |
| Negative attitude of suppliers toward supplying sustainable raw materials | | | | | | | | | A | O |
| Lack of supply chain partners' performance | | | | | | | | | | V |
| High cost of hazardous waste disposal | | | | | | | | | | |

### Formation of Initial Reachability Matrix (IRM)

Following the development of the Structural Self-Interaction Matrix (SSIM), the next step in the Interpretive Structural Modeling (ISM) approach involves constructing the initial Reachability Matrix (RM). This matrix quantifies the relationships between the ten identified barriers to implementing Sustainable Supply Chain Management (SSCM). It is derived by converting the symbolic representations from the SSIM into binary values: '1' indicates the presence of a relationship where one barrier influences another, while '0' signifies no direct relationship.

**Table 3: Reachability Matrix (RM)**

**Reachability Matrix(RM)**

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Driving Power |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High initial cost of implementation | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| Lack of knowledge and training in SSCM | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 8 |
| Lack of budget for SSCM implementation | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 6 |
| Lack of infrastructure facilities for SSCM implementation | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| Lack of supply chain support | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 4 |
| Lack of markets for recycled materials | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 3 |
| Lack of clear policies and practices | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 |
| Negative attitude of suppliers toward supplying sustainable raw materials | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 3 |
| Lack of supply chain partners' performance | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 5 |
| High cost of hazardous waste disposal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Dependence Power | 6 | 3 | 2 | 5 | 7 | 6 | 1 | 6 | 6 | 6 | |

The RM is populated systematically: the upper diagonal elements are filled directly from the SSIM, while the lower diagonal elements are derived using the fundamental steps of the ISM process, which account for both forward and backward relationships. This comprehensive approach ensures a complete representation of barrier interdependencies.

Two critical measures are derived from the RM: Driving Power and Dependence Power. Driving Power, displayed in the last column, reflects the extent to which a barrier influences other barriers. Dependence Power, shown in the bottom row, indicates the total influence a barrier receives from others. For instance, the barrier "Absence of clear policies and practices" exhibits the highest Driving Power (10), signifying its substantial impact on all other barriers.

The Reachability Matrix is a crucial tool in the ISM methodology as it helps identify key drivers and dependent barriers. By analyzing these relationships, decision-makers can prioritize actions to address the most influential obstacles, facilitating a more effective and strategic approach to overcoming SSCM implementation challenges.

**Final Reachability Matrix (FRM)**

To obtain the Final Reachability Matrix (FRM), the Initial Reachability Matrix (IRM) is further refined through an iterative process based on the dependency relationships. This step is crucial for capturing transitive relationships, where the influence of one barrier on another extends through intermediate variables.

The FRM provides a comprehensive view of the interconnections among the ten barriers to implementing Sustainable Supply Chain Management (SSCM) practices. In the matrix, a direct relationship between barriers is represented by '1,' while a transitive (indirect) relationship is denoted by '1.' This enhanced matrix reveals both immediate and extended influences, offering deeper insights into barrier interdependencies *.

**Table 4: Final Reachability Matrix (FRM)**

**Final Reachability Matrix(FRM)**

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Driving Power |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High initial cost of implementation | 1 | 0 | 0 | 1* | 1* | 1* | 0 | 1 | 1* | 1* | 7 |
| Lack of knowledge and training in SSCM | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 8 |
| Lack of budget for SSCM implementation | 1* | 1 | 1 | 1 | 1 | 1 | 0 | 1* | 1 | 1* | 9 |
| Lack of infrastructure facilities for SSCM implementation | 1 | 0 | 0 | 1 | 1 | 1* | 0 | 1 | 1 | 1 | 7 |
| Lack of supply chain support | 1 | 0 | 0 | 1* | 1 | 1* | 0 | 1* | 1 | 1 | 7 |
| Lack of markets for recycled materials | 1* | 0 | 0 | 1 | 1 | 1 | 0 | 1* | 1* | 1* | 7 |
| Lack of clear policies and practices | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 |
| Negative attitude of suppliers toward supplying sustainable raw materials | 1* | 0 | 0 | 1* | 1 | 1 | 0 | 1 | 1* | 1* | 7 |
| Lack of supply chain partners' performance | 1 | 0 | 0 | 1* | 1* | 1 | 0 | 1 | 1 | 1 | 7 |
| High cost of hazardous waste disposal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Dependence Power | 9 | 3 | 2 | 9 | 9 | 9 | 1 | 9 | 9 | 10 | |

Among the identified barriers, the "Absence of clear policies and practices" exhibits the highest Driving Power (10), indicating that it is a primary root cause affecting all other barriers. The Driving Power, presented in the column 12 of table 4, reflects the number of barriers influenced by a specific variable. Conversely, the Dependence Power, shown in the row 11 of table 4, indicates how strongly each barrier is affected by others.

By distinguishing between key drivers and dependent obstacles, the FRM enables decision-makers to prioritize efforts for addressing SSCM challenges. This systematic identification of critical barriers provides a strategic framework for overcoming implementation difficulties and facilitating sustainable supply chain practices.

**Classification of levels of barriers**

Following the computation of each barrier's cumulative score for Driving Power and Dependence Power, the next step involves assigning hierarchical levels to the identified barriers. This process is crucial for understanding the structural relationships and influence pathways among the barriers.

The level identification process begins by determining the *Reachability Set* and the *Antecedent Set* for each barrier. The Reachability Set includes the barrier itself and all other barriers it influences. Conversely, the Antecedent Set consists of the barrier itself and all barriers that affect it. The *Intersection Set* is derived by identifying the common elements shared between the Reachability and Antecedent Sets.

A barrier is assigned a specific level if its Reachability Set exactly matches its Intersection Set. Once a level is determined, the corresponding barrier is removed from further consideration. This iterative process continues until all barriers are categorized into distinct hierarchical levels.

This systematic classification aids in understanding the relative influence of each barrier, distinguishing between foundational barriers (drivers) and those that are dependent. Such insights are critical for developing targeted strategies to overcome obstacles and facilitate the successful implementation of Sustainable Supply Chain Management (SSCM) practices.

**Table 5: Level Partitioning**

**Level Partitioning(LP)**

| Elements(Mi) | Reachability Set R(Mi) | Antecedent Set A(Ni) | Intersection Set R(Mi)∩A(Ni) | Level |
|---|---|---|---|---|
| 1 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 2 | 2, | 2, 3, 7, | 2, | 3 |
| 3 | 3, | 3, 7, | 3, | 4 |
| 4 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 5 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 6 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 7 | 7, | 7, | 7, | 5 |
| 8 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 9 | 1, 4, 5, 6, 8, 9, | 1, 2, 3, 4, 5, 6, 7, 8, 9, | 1, 4, 5, 6, 8, 9, | 2 |
| 10 | 10, | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, | 10, | 1 |

## Digraph

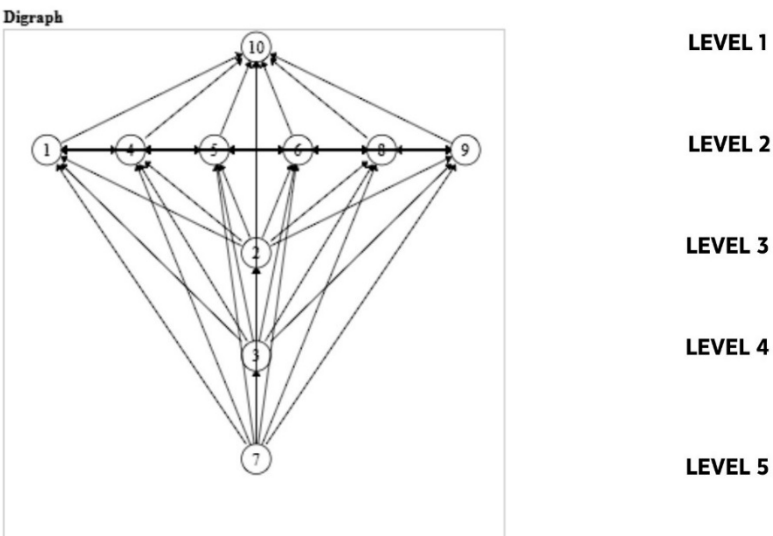


**Figure 3: Digraph**

A directed graph (Digraph) visually represents the hierarchical structure of a system by using nodes to denote components or variables and directed arrows to indicate relationships of influence or dependence. Each node in the graph is numbered (e.g., 1, 2, 3,…, 10) to correspond to a specific system component. The nodes are systematically arranged into five hierarchical levels based on the level partitioning presented in table 5, reflecting their relative influence and dependence. The digraph is presented in figure 3.

In the digraph, Node 10 is positioned at the top (Level 1) as the primary driver, exerting influence on other barriers. Level 2 comprises Nodes 1, 4, 5, 6, 8, and 9, which are directly influenced by Node 10 and, in turn, affect subsequent levels. Node 2 is located at Level 3, Node 3 at Level 4, and Node 7, the most dependent node, is positioned at the bottom (Level 5). As the hierarchy descends, nodes at higher levels exert influence on those below them, as indicated by the direction of the arrows. For instance, arrows extending from Level 2 to Levels 3, 4, and 5 depict the interdependencies among these components.

This graphical representation provides a clear and systematic visualization of the relationships within the system, distinguishing key drivers from dependent variables. Node 10, with its multiple outgoing arrows, represents the most influential barrier, while Node 7, influenced by all preceding levels, is the most dependent.

The Interpretive structural model presented in table 4 reveal that the "lack of clear policies and practices" is the primary barrier to adopting sustainable supply chain management (SSCM) and serves as the root cause of all other barriers. Ambiguous policies create confusion and a lack of direction for stakeholders, leading to insufficient "budget allocation for SSCM implementation." Without proper budgeting, businesses face challenges in funding critical areas such as infrastructure development, information sharing, and employee training. As a result, the "lack of knowledge and training in SSCM" leaves employees and supply chain partners ill-equipped to adopt and effectively implement sustainable practices.

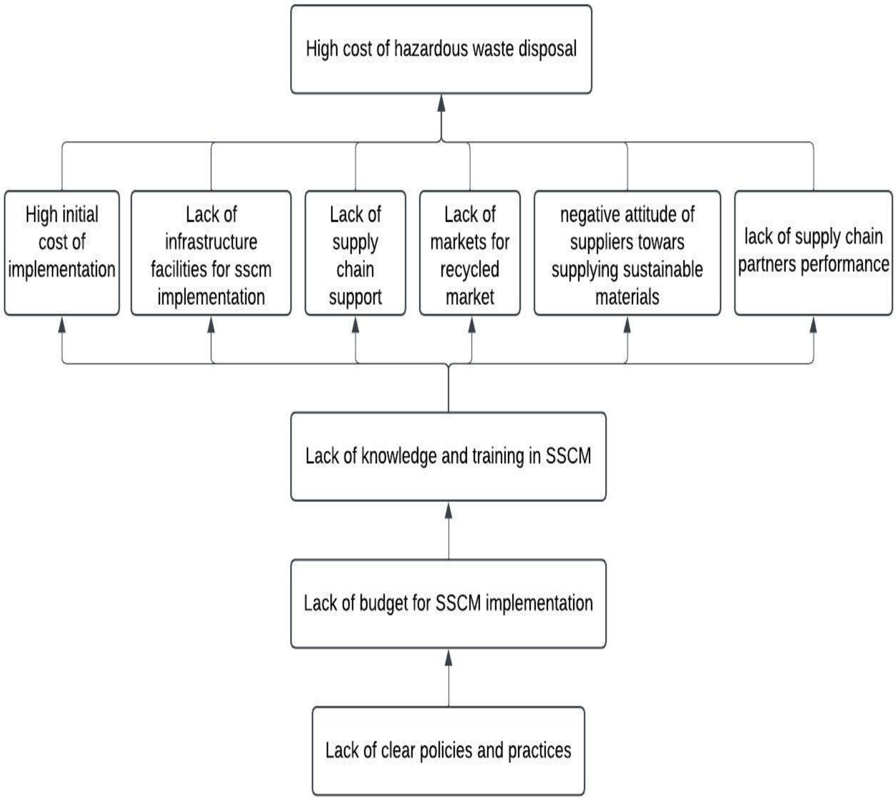


**Figure 4: Interpretive structural model**

The absence of clear policies also contributes to increased costs and inefficiencies, further amplifying barriers like the "high initial implementation costs." Without structured guidelines, companies resort to inconsistent and ineffective practices, driving up expenses. Similarly, policy frameworks play a crucial role in directing infrastructure investments. In their absence, organizations experience a "lack of infrastructure facilities for SSCM implementation," which hinders the seamless adoption of sustainable practices.

Moreover, the "lack of markets for recycled materials" and the "negative attitudes of suppliers toward sustainable materials" stem from the absence of clear regulations and incentives that would otherwise encourage sustainable practices. Fragmented responsibilities and poor coordination—caused by unclear policies—further worsen the "poor performance of supply chain partners."

By addressing the "lack of clear policies and practices," these interconnected barriers can be systematically mitigated. In the textile industry, resolving this root cause will facilitate a more efficient and sustainable supply chain, fostering long-term environmental and operational benefits.

**MICMAC analysis**

MICMAC (Matrix of Cross-Impact Multiplication Applied to a Classification) analysis is a strategic method used to examine the interconnections between various elements or barriers within a system. It categorizes variables based on their driving and dependence power, helping to identify the primary drivers and dependent factors that influence a particular system. MICMAC analysis is especially valuable in complex systems such as Sustainable Supply Chain Management (SSCM), where numerous interrelated obstacles make it challenging to prioritize and manage them effectively.

MICMAC analysis categorizes barriers into four groups:

1. Drivers – Variables with high driving power and low dependence, which act as the root causes influencing other barriers.
2. Dependent Variables – Variables with low driving power and high dependence, which are outcomes influenced by other factors.
3. Linkage Variables – Variables with both high driving and dependence power, which are highly interconnected and sensitive to changes.
4. Independent Variables – Variables with low driving and dependence power, which are weakly connected to the system.

The MICMAC analysis is visually represented through a graph - figure 5, where the X-axis (horizontal) indicates the Dependence Power of the variables, ranging from left to right (0 to 10), and the Y-axis (vertical) represents the Driving Power, ranging from bottom to top (0 to 10). This graphical representation divides the variables into the four quadrants, providing a clear depiction of their influence and interdependencies within the SSCM system. Using data from the Final Reachability

Matrix (FRM) presented in Table 4, MICMAC analysis classifies the ten barriers to SSCM implementation according to their driving and dependence power. For instance, the barrier "Lack of clear policies and practices" exhibits the highest driving power (10), significantly influencing other barriers. Conversely, barriers such as the "High cost of hazardous waste disposal," which exhibit low driving and dependence power, may not directly influence other barriers but still warrant attention.

The numbered dots on the graph represent specific variables. For instance, variables 1, 4, 5, 6, 8, and 9 fall within Quadrant III (Linkage Variables), highlighting their dual role as both influencers and dependents. Variables 2 and 3, located in Quadrant IV (Independent Variables), demonstrate strong driving power with minimal dependence on others. Variable 7, positioned near the top of the graph, exhibits the highest driving power and the lowest dependence, making it a critical driver. Conversely, variables in Quadrant I are considered less influential within the system.

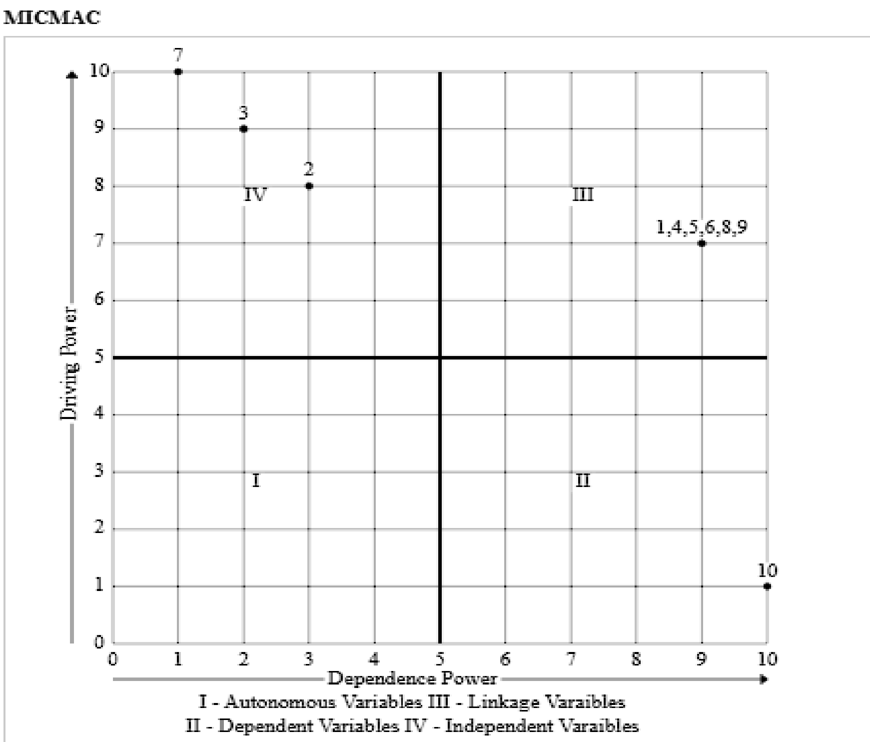


**Figure 5: MICMAC graph**

The MICMAC classification provides a systematic understanding of how different barriers interact, helping prioritize efforts to address the most impactful challenges in Sustainable Supply Chain Management (SSCM).

## 4 Results and discussion

The findings of this study provide a comprehensive understanding of the barriers to implementing Sustainable Supply Chain Management (SSCM) in Kerala's textile manufacturing sector through the application of the ISM-MICMAC approach. By systematically analyzing the interrelationships between these barriers, the study identifies the "lack of clear policies and practices" as the root cause barrier with the highest driving power and minimal dependency. This insight emphasizes the fundamental role of policy frameworks in shaping the adoption of SSCM practices and suggests that addressing this core barrier can create a cascading effect to mitigate other challenges.

A key implication of the study is that without clear SSCM policies, organizations face ambiguity in resource allocation, investment planning, and stakeholder engagement. This ambiguity not only inhibits the establishment of structured sustainability initiatives but also exacerbates downstream challenges such as insufficient infrastructure and budget constraints. The lack of policy direction reduces the incentive for organizations to invest in training programs and collaborate with supply chain partners, thereby limiting the overall effectiveness of SSCM implementation. This finding aligns with previous literature emphasizing the role of regulatory frameworks in facilitating sustainable practices and suggests that policymakers should prioritize the development of comprehensive SSCM guidelines to provide a clear roadmap for industry stakeholders.

The study further highlights the role of connecting barriers, including high initial implementation costs, inadequate infrastructure, and unfavorable supplier attitudes. These barriers exhibit both high driving and dependency power, indicating their pivotal position in sustaining or alleviating systemic challenges. High initial costs remain a persistent obstacle, particularly for small and medium-sized enterprises (SMEs), due to the substantial financial burden associated with adopting sustainable technologies, improving waste management systems, and providing personnel training. Addressing these barriers requires coordinated action through publicprivate partnerships to subsidize infrastructure development and provide financial incentives for sustainable investments.

The MICMAC analysis reveals that the "high cost of hazardous waste disposal" functions as a dependent barrier with minimal driving power. This indicates that waste management costs are largely symptomatic of upstream inefficiencies, such as the absence of clear policies and limited financial support. This finding underscores the need to address structural and policy-level issues to alleviate the financial burden of hazardous waste disposal. Establishing well-defined waste management regulations and providing economic incentives for waste reduction could help mitigate these dependent barriers and promote a circular economy within the textile sector.

Another critical insight from the study is the influence of knowledge gaps on SSCM implementation. Insufficient training and awareness hinder the ability of employees and supply chain partners to engage with sustainable practices effectively. This suggests that developing targeted education programs and conducting awareness campaigns are essential to bridge these gaps. By enhancing stakeholder knowledge, organizations can facilitate better decision-making, improve compliance with environmental standards, and foster a culture of sustainability.

The study's findings also point to the necessity of fostering collaboration across the supply chain to overcome resistance from suppliers and ensure cohesive implementation of SSCM practices. Supplier reluctance often stems from concerns about increased operational costs and market uncertainty for sustainable products. Therefore, improving supplier engagement through collaborative platforms, joint sustainability initiatives, and long-term contractual agreements can mitigate resistance and align incentives.

In summary, the ISM-MICMAC approach provides a structured framework to identify and prioritize the most influential barriers to SSCM adoption. The study emphasizes that addressing root-cause barriers, particularly the lack of clear policies, is paramount for fostering sustainable practices. Complementary measures such as infrastructure investment, financial support, and comprehensive training programs are also critical to overcoming connecting and dependent barriers. By implementing these strategies, the textile manufacturing sector in Kerala can achieve more effective and sustainable supply chain management while advancing broader environmental and economic goals.

## 5 Conclusions

This study underscores the critical role of clear policies and practices in facilitating the adoption of Sustainable Supply Chain Management (SSCM) within Kerala's textile manufacturing sector. Among the eleven identified barriers, the "lack of clear policies and practices" emerged as the most influential driving factor. Addressing this foundational issue is essential, as unclear policies lead to systemic inefficiencies, including inadequate infrastructure investments, insufficient training initiatives, and poor budget allocation. These inefficiencies amplify the high upfront implementation costs and diminish the overall performance of supply chain participants.

The ISM-MICMAC analysis further revealed several key connecting barriers, such as high implementation costs, inadequate infrastructure, hostile supplier attitudes, and subpar supply chain partner performance. These barriers exhibit both significant driving and dependency powers, acting as intermediaries that propagate challenges across the supply chain. Overcoming these linking barriers requires a comprehensive and coordinated strategy involving active stakeholder engagement, legislative reforms, and targeted infrastructure investments.

A particularly noteworthy finding is that the "high cost of hazardous waste disposal" functions as a dependent variable with low driving power. This barrier is largely a consequence of upstream inefficiencies, highlighting the importance of addressing root causes and intermediary obstacles to mitigate its impact.

To successfully implement SSCM, the study emphasizes the necessity of establishing well-defined and enforceable policies. Clear guidelines provide a structured framework that facilitates sustainable practices, optimizes resource allocation, modernizes infrastructure, and fosters greater supplier participation. Additionally, targeted initiatives such as awareness campaigns, capacity-building programs, and the expansion of markets for sustainable products are crucial in addressing the connecting barriers.

By adopting a holistic and strategic approach, Kerala's textile industry can effectively navigate the complexities of SSCM implementation and advance toward achieving long-term sustainability goals. The insights from this research offer a valuable foundation for future studies and practical interventions in sustainable supply chain management, providing a roadmap for industries seeking to enhance sustainability within their operations.

**References**

Adams, D., Donovan, J., & Topple, C. (2022). Sustainability in large food and beverage companies and their supply chains: An investigation into key drivers and barriers affecting sustainability strategies. *Business Strategy and the Environment, 32*(4), 1451–1463. https://doi.org/10.1002/bse.3198

Dubey, R., Gunasekaran, A., & Papadopoulos, T. (2017). Green supply chain management: Theoretical framework and further research directions. *Benchmarking: An International Journal, 24*(1), 184–218. https://doi.org/10.1108/bij-01-2016-0011

Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. (2013). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International Journal of Production Economics, 147*, 555–568. https://doi.org/10.1016/j.ijpe.2013.08.018

Kulkarni, A., Joseph, S. and Patil, K. (2023), "Role of Artificial Intelligence in Sustainability Reporting by Leveraging ESG Theory into Action", *International Conference on Advancement in Computation & Computer Technologies*, 795–800, doi: 10.1109/incacct57535.2023.10141584.

Kumar, T.S., Muthuvelammai, S. and Jayachandran, N. (2024), AI in Textiles: A Review of Emerging Trends and Applications, *International Journal for Research in Applied Science and Engineering Technology*, 12 (9), 1663–1678, doi: 10.22214/ijraset.2024.64404.

Luthra, S., Garg, D., & Haleem, A. (2014). Critical success factors of green supply chain management for achieving sustainability in Indian automobile industry. *Production Planning & Control, 26*(5), 339–362. https://doi.org/10.1080/09537287.2014.904532

Majumdar, A., & Sinha, S. K. (2018). Analyzing the barriers of green textile supply chain management in Southeast Asia using interpretive structural modeling. *Sustainable Production and Consumption, 17*, 176–187. https://doi.org/10.1016/j.spc.2018.10.005

Mangla, S. K., Luthra, S., Mishra, N., Singh, A., Rana, N. P., Dora, M., & Dwivedi, Y. (2018). Barriers to effective circular supply chain management in a developing country context. *Production Planning & Control, 29*(6), 551–569. https://doi.org/10.1080/09537287.2018.1449265

Moktadir, M. A., Ali, S. M., Rajesh, R., & Paul, S. K. (2018). Modeling the interrelationships among barriers to sustainable supply chain management in leather industry. *Journal of Cleaner Production, 181*, 631–651. https://doi.org/10.1016/j.jclepro.2018.01.245

Reenu, N., Singh, S., Vig, S. and Dwivedi, S. (2024), Impact of uses of Artificial Intelligence (AI) in Textile Industry in India, *2022 13th International Conference on Computing Communication and Networking Technologies (ICCCNT)*, pp. 1–9, doi: 10.1109/icccnt61001.2024.10725995.

Viswakarma, A., Dangayach, G. S., Meena, M. L., & Gupta, S. (2022). Analysing barriers of sustainable supply chain in apparel & textile sector: A hybrid ISM-MICMAC and DEMATEL approach. *Cleaner Logistics and Supply Chain, 4*, 100073. https://doi.org/10.1016/j.clscn.2022.100073