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Identifying And Prioritizing Barriers To Circular Supply Chain Management Adoption In Indian Manufacturing: A Fuzzy AHP-Based Analysis

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Abstract:
The transition from a linear to a circular supply chain model is a vital strategic move for achieving sustainable development in Indian manufacturing industries. However, this transformation is fraught with significant challenges that obstruct the effective adoption of Circular Supply Chain Management (CSCM) practices. This study aims to identify, categorize, and prioritize critical barriers that hinder CSCM implementation in the Indian context. Through an extensive literature review and expert consultations, thirty key barriers were identified and classified into five thematic categories: Structural & Technical, Resource & Financial, Policy & Regulatory, Organizational & Strategic, and Awareness & Cultural. The Fuzzy Analytic Hierarchy Process (Fuzzy AHP) was applied to systematically evaluate the relative significance of each barrier, incorporating expert judgment and addressing the inherent uncertainty in decision-making. The results reveal that "Lack of Awareness and Understanding," "High Initial Investment Costs," and "Resistance to Change" are the most influential barriers to CSCM adoption. Structural and technical issues such as "Inadequate Recycling Facilities" and "Inefficient Reverse Logistics" also emerged as significant impediments. Furthermore, the study presents visual insights through charts and tables, aiding in understanding the hierarchical influence of these barriers. The findings are corroborated with existing literature and offer valuable guidance to policymakers, supply chain managers, and sustainability strategists in formulating targeted interventions. This research contributes to the growing body of knowledge on sustainable supply chain transformation and provides a decision-support framework for overcoming practical challenges in implementing CSCM in developing economies like India.
Keywords: *Prioritizing Barriers, Circular Supply Chain, Fuzzy Analytic Hierarchy Process (Fuzzy AHP)*

1. INTRODUCTION

In recent decades, the escalating environmental degradation and unsustainable consumption of finite resources have drawn global attention to the limitations of the traditional linear economy model, which is based on the 'take-make-dispose' paradigm. This system, though foundational to industrial development, has led to alarming levels of resource depletion, waste generation, and greenhouse gas emissions. Against this backdrop, the concept of the Circular Economy (CE) has emerged as a compelling and pragmatic approach for sustainable development. Circular economy promotes resource efficiency, waste minimization, product lifecycle extension, and regenerative design by closing material loops and decoupling economic growth from resource consumption.

Circular Supply Chain Management (CSCM), an operational subset of CE, is rapidly gaining traction as a transformative strategy that integrates circularity principles into conventional supply chain operations. Unlike traditional supply chains that end with product disposal, CSCM emphasizes returning materials back into the production cycle through practices such as remanufacturing, refurbishing, recycling, and product take-back systems. It reimagines supply chain design by focusing on reverse logistics, resource recovery, closed-loop systems, and cross-industry collaboration. Thus, CSCM serves as a critical lever for achieving sustainability in the manufacturing and industrial sectors.

In the Indian context, CSCM has garnered increasing relevance due to the nation's growing industrial base, urbanization, and mounting waste management challenges. India generates over 62 million tonnes of waste annually, with only a fraction being scientifically processed. Moreover, the Indian manufacturing sector, which contributes around 17% to the national GDP, remains predominantly linear in its operations. With mounting regulatory pressure, shifting consumer expectations, and India's commitments under international agreements such as the Paris Accord and SDG 12 (Responsible Consumption and Production), the transition to CSCM is no longer optional but imperative.

Despite the evident benefits of CSCM—such as resource conservation, cost savings, improved brand image, and regulatory compliance—its implementation in Indian manufacturing industries remains limited. This disconnect raises a critical question: What are the key barriers hindering the adoption of CSCM in Indian manufacturing? Understanding these barriers is essential to facilitate a smoother transition toward circularity and to formulate actionable strategies for industry stakeholders and policymakers.

While global interest in CSCM is growing, the Indian industrial landscape presents a unique set of challenges and constraints that hinder its effective adoption. Several studies conducted in developed economies have explored the adoption of circular practices, yet the contextual realities of developing nations, such as India, are often vastly different. These differences arise due to factors such as limited infrastructure, fragmented supply chains, lack of formal recycling systems, unorganized informal sectors, financial constraints, and a general lack of awareness among stakeholders.

Furthermore, the Indian manufacturing sector is characterized by the dominance of Small and Medium Enterprises (SMEs), which often lack the financial resources and technical expertise to implement complex CSCM frameworks. The informal recycling economy, though extensive, operates without standardization, compliance, or technological integration, often leading to inefficient and unsafe practices. Regulatory support, though improving, still lacks the specificity and enforcement mechanisms required to incentivize or mandate circularity in supply chains.

Academically, there is a visible research gap in identifying, categorizing, and ranking the critical barriers to CSCM adoption specifically in the Indian context. Most of the existing literature either broadly discusses sustainability in supply chains or addresses CE implementation in silos. There is limited empirical or analytical work that focuses exclusively on CSCM and its implementation challenges in Indian manufacturing industries. Without a thorough understanding of these barriers, policy interventions and managerial strategies may fail to address root causes, thus stalling progress.

Moreover, industry practitioners often struggle with vague or generalized guidelines for CSCM adoption. An evidence-based and India-specific framework that outlines the key barriers can offer valuable insights to practitioners, industry bodies, and policymakers. It can help in resource allocation, training needs identification, regulatory planning, and the design of incentive mechanisms.

Given this scenario, there is a pressing need for a comprehensive, structured, and contextually grounded study that identifies and analyzes the barriers to CSCM adoption in Indian manufacturing industries. This study intends to fill that gap and serve as a foundational step toward enabling sustainable industrial transformation.

The overarching aim of this research is to systematically investigate the barriers that obstruct the effective implementation of Circular Supply Chain Management in Indian manufacturing industries. To achieve this aim, the study is guided by the following specific objectives:

- To review and synthesize existing literature on circular supply chain management and identify a preliminary list of barriers reported globally and in developing economies.
- To categorize and classify the identified barriers into meaningful dimensions, such as organizational, technological, regulatory, operational, and cultural factors.
- To assess the relative importance and influence of these barriers using Multi-Criteria Decision-Making (MCDM) approach
- To provide strategic recommendations for Indian manufacturers, policymakers, and supply chain professionals to overcome or mitigate these barriers and facilitate CSCM adoption.

The research also aims to contribute to theory-building in the domain of sustainable supply chain management by expanding the discourse around CSCM in emerging economies like India. By identifying the most pressing and influential barriers, this study can also help prioritize policy actions and direct future research toward high-impact problem areas. The remainder of this paper is structured as follows. Section 2 presents a detailed literature review of CSCM, highlighting the theoretical background, global perspectives, and existing research on implementation challenges. Section 3 outlines the research methodology, including barrier identification, classification, expert consultation, and the use of analytical models. Section 4 presents the results and analysis, focusing on the prioritization of identified barriers using the selected analytical framework. Section 5 offers a comprehensive discussion on the implications of the findings for industry and policy, as well as managerial strategies followed by a summary of key findings, limitations, and directions for future research.

2. LITERATURE REVIEW

2.1 Circular Economy and the Supply Chain Context

The concept of the CE has gained prominence as a sustainable alternative to the traditional linear economy. CE aims to decouple economic growth from resource consumption and waste generation by promoting strategies such as reuse, remanufacturing, recycling, and sustainable product design. Geissdoerfer et al. (2017) define the circular economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops.

The CSCM approach extends the CE philosophy across the entire supply chain, integrating reverse logistics, resource recovery, sustainable sourcing, and product lifecycle extension. CSCM represents a strategic approach for reducing environmental impacts, enhancing resource efficiency, and improving the competitiveness of firms through closed-loop material flows (Govindan & Hasanagic, 2018). Unlike traditional supply chain models that focus on forward movement of goods and linear consumption patterns, CSCM enables the reintegration of products and materials at various lifecycle stages, enabling zero-waste production systems.

Researchers have highlighted the benefits of CSCM such as cost reduction, regulatory compliance, improved brand value, and enhanced customer loyalty (Kazancoglu et al., 2020). However, the transition from linear to circular models in supply chain operations is fraught with barriers, especially in developing economies. Understanding these challenges is crucial for operationalizing circularity at scale.

2.2 Barriers to CSCM Implementation: Global Insights

The literature identifies a wide range of barriers that hinder the adoption of CSCM across industries and geographies. These barriers span organizational, technical, financial, and cultural dimensions. Ritzén and Sandström (2017) classify CSCM implementation challenges into internal (e.g., lack of top management commitment, organizational inertia) and external (e.g., weak legislation, limited customer awareness) categories.

De Angelis et al. (2018) emphasize that supply chain complexity and lack of coordination among stakeholders are major obstacles to implementing circular practices, especially when multiple tiers of suppliers and logistics partners are involved. Technological barriers, such as lack of digital tracking systems, IoT integration, and data interoperability, also prevent effective material recovery and reverse logistics execution.

Financial constraints are another widely cited barrier. Many businesses, particularly SMEs, perceive circular initiatives as costly and risky due to high initial investments in infrastructure, retrofitting, and training. Kirchherr et al. (2018) argue that while circularity is conceptually attractive, it often lacks practical traction due to "soft" barriers like resistance to change, lack of knowledge, and behavioral inertia.

Policy and regulatory issues also influence CSCM adoption. Studies in Europe, China, and Latin America indicate that unclear or inadequate policy frameworks, lack of financial incentives, and poor enforcement of extended producer responsibility (EPR) policies can significantly impede progress toward circularity. These barriers highlight the importance of a systems-level approach that aligns government policy, business strategy, and societal awareness.

2.3 CSCM Barriers in the Indian Manufacturing Sector

Although global literature provides valuable insights, there is a notable lack of studies focused on the barriers to CSCM in the Indian context, where socio-economic, infrastructural, and regulatory conditions differ significantly from those in developed nations. India presents a paradoxical situation—while it is one of the largest producers of waste, it also has a robust informal recycling economy. However, the lack of standardization, low technology penetration, and weak integration with formal supply chains often make circular practices ineffective.

Sharma et al. (2021) identify challenges such as low consumer awareness, inadequate infrastructure, lack of government incentives, and absence of industry standards as significant impediments to circular economy adoption in India. Mishra et al. (2020) point out that Indian industries, particularly SMEs, operate on thin profit margins and are risk-averse, which makes them reluctant to invest in circular initiatives that do not promise short-term returns.

A key challenge in India is the fragmented nature of supply chains. Manufacturers rely on multiple tiers of suppliers with varying capacities, technologies, and environmental awareness, which makes uniform circular implementation difficult. Furthermore, the lack of advanced technologies like Artificial Intelligence, IoT, Blockchain, and Big Data in many small and medium industries limits traceability, monitoring, and lifecycle analysis of products and materials.

The reverse logistics ecosystem in India is underdeveloped. Collection systems for end-of-life products, especially in rural and semi-urban areas, are either absent or inefficient. Without a robust reverse logistics framework, material recovery and closed-loop production become practically impossible. Additionally, informal waste pickers, although crucial in waste recovery, operate outside formal channels, which leads to inconsistent and suboptimal recycling outcomes.

Another significant barrier in India is the deficiency of skilled human resources. There is a lack of training and education on sustainability, circular economy practices, and green design thinking in most technical institutes and management programs. This results in a workforce that is ill-equipped to plan or execute CSCM strategies.

From a policy standpoint, although the Ministry of Environment, Forest and Climate Change (MoEFCC) and NITI Aayog have published circular economy frameworks for select sectors, the enforcement remains weak, and adoption is largely voluntary. A well-defined legal structure, combined with performance-based incentives, is currently missing.

2.4 Classification of Barriers

To systematically analyze the literature and guide empirical investigation, scholars have proposed various classification frameworks for CSCM barriers. For instance, Zhu and Geng (2013) categorize barriers into organizational, technological, institutional, and market-related. Similarly, Bressanelli et al. (2018) suggest a structure based on product lifecycle stages, such as design, production, usage, and end-of-life.

In the Indian context, a practical classification could include: Organizational Barriers: lack of leadership support, short-termism, and absence of internal capabilities. Technological Barriers: low adoption of enabling technologies, quality inconsistency in recycled materials. Regulatory and Policy Barriers: absence of strong laws, limited government incentives. Cultural and Behavioral Barriers: resistance to product reuse, low consumer awareness. Operational Barriers: inefficient reverse logistics, poor supplier integration, and high implementation costs. This study adopts a multi-dimensional classification to comprehensively capture the complex and interrelated nature of these barriers. The identification and grouping of barriers are further refined through expert inputs and analytical validation.

2.5 Research Gaps and Contributions

Despite the growing interest in CSCM, particularly in the Global South, the academic literature still lacks a context-specific and empirically validated barrier framework for Indian manufacturing industries. Most studies are either conceptual or limited to isolated sectors such as e-waste or plastics. There is little use of multi-criteria decision-making (MCDM) techniques like Fuzzy AHP or ISM-MICMAC to prioritize the barriers based on influence and dependency, which is essential for practical decision-making. This study attempts to bridge these gaps by identifying a comprehensive list of CSCM barriers through a combination of literature review and expert consultation. Also, through categorizing the barriers into logical themes that reflect the Indian industrial context. Furthermore by prioritizing these barriers using analytical tools to guide strategic interventions and offering actionable recommendations for manufacturers, supply chain professionals, and policymakers.

3. METHODOLOGY

3.1 Overview of the Fuzzy AHP Method

The Analytic Hierarchy Process (AHP), developed by Saaty (1980), is a powerful multi-criteria decision-making (MCDM) tool widely used to analyze complex decision problems. It breaks down a problem into a hierarchy of more manageable sub-problems, each of which can be analyzed independently. However, AHP in its traditional form uses crisp numbers, which often fail to capture the vagueness and ambiguity inherent in human judgment.

To overcome this limitation, researchers introduced Fuzzy AHP, which integrates fuzzy logic with AHP. Fuzzy logic, introduced by Zadeh (1965), deals with the concept of partial truth—truth values between "completely true" and "completely false"—making it an ideal approach when dealing with uncertain or imprecise expert evaluations.

In the context of this study, the Fuzzy AHP method is employed to evaluate and rank the critical barriers to CSCM implementation in the Indian manufacturing sector. The fuzzy approach enables a more realistic assessment of expert opinions by using triangular fuzzy numbers (TFNs) to express preferences in pairwise comparisons.

3.2 Step-by-Step Procedure of Fuzzy AHP

The following steps were followed in applying the Fuzzy AHP methodology:

Step 1: Define the Goal and Criteria (Barriers)

The goal of the study is to prioritize the critical barriers to Circular Supply Chain Management (CSCM) in Indian manufacturing. Based on extensive literature review and expert input, 30 barriers were identified and classified into categories. These barriers serve as the decision criteria in the fuzzy AHP hierarchy.

Step 2: Construct the Hierarchical Structure

The AHP structure consists of three levels:

- Level 1 (Goal): Prioritization of CSCM Barriers
- Level 2 (Criteria): Five main categories (e.g., Organizational, Technological, Policy & Regulatory, Cultural & Behavioral, Operational)
- Level 3 (Sub-criteria): Specific barriers under each main category (as finalized in the previous step)

Step 3: Generate Pairwise Comparison Matrices

Experts are asked to compare each pair of barriers within a category based on their relative importance in contributing to CSCM implementation difficulty. These comparisons are made using linguistic variables, such as:

Table 1- Linguistic table for TFN conversion

Linguistic Term	Triangular Fuzzy Number (TFN)
Equally Important	(1, 1, 1)
Weakly More Important	(1, 3, 5)
Strongly More Important	(3, 5, 7)
Very Strongly Important	(5, 7, 9)
Absolutely Important	(7, 9, 9)

Step 4: Build the fuzzy pairwise comparison matrix (FPCM)

After specifying the adopted scale, the next step involves consulting the decision group panel for preparing the fuzzy pairwise comparison matrix (FPCM) for the selected criteria's and sub criteria's with the help of TFN. A FPCM $\tilde{X}$ is though developed by doing pairwise comparison among the defined criteria.

$$\tilde{X}^{\alpha} = \begin{bmatrix} 1 & \tilde{x}^{\alpha}_{12} & \cdots & \cdots & \cdots & \tilde{x}^{\alpha}_{1n} \\ \tilde{x}^{\alpha}_{21} & 1 & \cdots & \cdots & \cdots & \tilde{x}^{\alpha}_{2n} \\ \cdots & \cdots & 1 & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ \tilde{x}^{\alpha}_{n1} & \tilde{x}^{\alpha}_{n2} & \cdots & \cdots & \cdots & 1 \end{bmatrix}$$

Here $\tilde{x}_{ij} = 1$, if i is similar to j and $\tilde{x}_{ij} = (\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9})$ or $\tilde{1}^{-1}, \tilde{3}^{-1}, \ldots, \tilde{9}^{-1}$ if the value of i is not similar to j. This particularly means the importance of i criteria over j criteria corresponding to the TFN scale. When a criteria of importance $\tilde{x}_{ij}$ is allotted to a specific set then automatically the reciprocal entry is allotted to the $\tilde{x}_{ji}$ entry.

Step 5: Transition of FCM into Crisp Comparison Matrix (CCM)

In order to rank the triangular fuzzy numbers α-cut method is used in the present study. The α-cut exhibits the capability to unify the decision group panel's assurance on the assessments made for FCM build in the previous step. It includes set of value from a fuzzy number. So for α = 0.5 we will take the set (2,3,4).

Once the value of α is defined, the comparison matrix for α-cut can be formed with the help of FCM after setting the degree of optimism μ, needed for calculating the level of atonement.

$$\tilde{X}^{\alpha} = \begin{bmatrix} 1 & \tilde{x}^{\alpha}_{12} & \cdots & \cdots & \cdots & \tilde{x}^{\alpha}_{1n} \\ \tilde{x}^{\alpha}_{21} & 1 & \cdots & \cdots & \cdots & \tilde{x}^{\alpha}_{2n} \\ \cdots & \cdots & 1 & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ \tilde{x}^{\alpha}_{n1} & \tilde{x}^{\alpha}_{n2} & \cdots & \cdots & \cdots & 1 \end{bmatrix}$$

The level of atonement for the assessment matrix is calculated by degree of optimism of the decision group panel. As the value of μ increases, it reflects in enhancement of degree of optimism. The index of optimism is a linear convex combination and is illustrated by given equation.

$$\tilde{x}^{\alpha}_{ij} = \mu \tilde{x}^{\alpha}_{ijl} + (1-\mu)\, \tilde{x}^{\alpha}_{iju} \quad \text{where } 0 \leq \mu \leq 1$$

By incorporating the μ value in above equation, the α-cut FCM is transposed into CCM X.

$$X = \begin{bmatrix} 1 & x_{12} & \cdots & \cdots & \cdots & x_{1n} \\ x_{21} & 1 & \cdots & \cdots & \cdots & x_{2n} \\ \cdots & \cdots & 1 & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & 1 & \cdots \\ x_{n1} & x_{n2} & \cdots & \cdots & \cdots & 1 \end{bmatrix}$$

Step 6: Carry out the check for consistency

Synchronization among the judgements made by the decision group panel is extremely important to obtain the precise results from fuzzy AHP. Hence the check for consistency is enormously significant to assess the similarity in the assessments made by the decision makers. For each developed matrix and the entire hierarchy, consistency ratio is calculated in order to control the final results of the applied method. If X is consistent then it simply indicates that FCM $\tilde{X}$ is consistent too. The same is computed through the CR value.

$$CR = \frac{CI}{RI}$$

where CI represents consistency index and RI denotes random index.

$$CI = \frac{\lambda_{max} - n}{n-1}$$

λ_{max} is the highest eigen value obtained for the selected matrix and n denotes the order of matrix.

Step 7: Compute the final weights
According to crisp comparison matrix X the weight criteria is determined by following certain steps.
a) Compute the column sum for each element of each column.
b) Use the column sum of each column to divide their respective element.
c) Compute the row sum for each row of the matrix and divide each row sum by the order of matrix (ie. criteria included in the selected matrix), as this will reflect the corresponding weight of the criteria.

3.4 Data Collection and Expert Input

To implement Fuzzy AHP, expert input is essential. In this study, a panel of 12 experts was consulted, comprising of 4 academicians specializing in supply chain and sustainability. Four senior managers from Indian manufacturing industries (automotive, electronics, and FMCG) and four policy and circular economy consultants. Experts provided pairwise comparisons for all barriers within each category based on their experience, judgment, and industry observations. Responses were aggregated, and fuzzy matrices were constructed accordingly.

4. **RESULTS AND DISCUSSION**

This section presents and interprets the findings of the Fuzzy AHP used to prioritize critical barriers obstructing the adoption of CSCM in Indian manufacturing industries. The results provide a comprehensive view of the relative importance of various barriers across five broad categories: organizational, technological, policy and regulatory, cultural and behavioral, and operational. The expert-based fuzzy AHP model generated defuzzified scores for each identified barriers. These scores were ranked to reveal the most influential impediments to CSCM implementation.

4.1 Prioritization of CSCM Barriers: Fuzzy AHP Results

The top 10 most critical barriers computed through the said MCDM approach are as follows:

Table 2- CSCM barrier weights computed through fuzzy AHP

Rank	**CSCM Barrier**	**Fuzzy AHP Weight**
1	Supply Chain Complexity	0.059
2	Quality Variability in Recycled Materials	0.065
3	Lack of Technology Adoption	0.069
4	Inadequate Recycling Facilities	0.072
5	Inefficient Reverse Logistics	0.076
6	Limited Financial Support	0.081
7	Weak Regulatory Framework	0.085
8	Resistance to Change	0.092
9	High Initial Investment Costs	0.098
10	Lack of Awareness and Understanding	0.103

These results indicate that awareness, infrastructure, financial viability, and institutional readiness are the leading challenges in transitioning from linear to circular supply chains in the Indian context.

4.2 Discussion of Key Barriers

4.2.1 Lack of Awareness and Understanding

The top-ranked barrier—lack of awareness—demonstrates the foundational issue plaguing CSCM adoption. Many small and medium-scale enterprises (SMEs), which form the backbone of Indian manufacturing, operate with limited exposure to sustainability concepts. This aligns with earlier findings by Kazancoglu et al. (2020) and Govindan and Hasanagic (2018), who emphasized that a significant portion of manufacturing firms are unaware of the environmental and economic benefits of circular supply chains. The lack of formal training and poor integration of circular economy concepts into management curricula further exacerbates this issue.

4.2.2 High Initial Investment Costs

Ranked second, the cost-intensive nature of CSCM implementation is a well-documented concern. Transitioning from linear models to circular ones requires investment in reverse logistics, recycling equipment, sustainable materials, and employee upskilling. Studies such as Singh and Ordoñez (2016) and Ghisellini et al. (2016) confirm that capital expenditure remains a major bottleneck in low- and middle-income economies. Furthermore, with tight margins and inconsistent returns, manufacturers find it difficult to justify such investments without clear, short-term benefits.

4.2.3 Resistance to Change

Organizational inertia ranks third, highlighting the cultural and structural rigidity of many manufacturing setups in India. Employees and top management often resist abandoning legacy systems due to comfort, familiarity, and the fear of disruptions. This resonates with Zhu et al. (2010) and Prieto-Sandoval et al. (2018), who noted that change resistance is particularly severe in traditionally hierarchical industries such as textiles, automotive, and steel manufacturing.

4.2.4 Inefficient Reverse Logistics

The fourth-ranked barrier, inefficient reverse logistics, stems from the lack of a dedicated framework for recollection, sorting, and redistribution of end-of-life products. Indian logistics infrastructure largely supports forward supply chains, while the reverse flow of materials remains fragmented and cost-intensive. This observation is supported by Bressanelli et al. (2018) and Ravi and Shankar (2005), who emphasized that the absence of a reverse supply chain network is a critical constraint in product recovery.

4.2.5 Inadequate Recycling Facilities

The poor state of recycling infrastructure, especially in Tier 2 and Tier 3 cities, adds another layer of complexity. Without high-capacity and technologically advanced recycling plants, materials lose their value, leading to landfilling or incineration. According to Indian Resource Panel Report (2019), more than 70% of recyclable waste in India is processed informally, causing inefficiencies, health hazards, and quality issues in recovered materials.

4.3 Cross-Comparative Analysis with Past Literature

To validate the robustness of our findings, the results were compared with earlier studies across global and Indian contexts:

Table 3- Comparative analysis of top barriers reported in literature

Study	**Top Barriers Identified**	**Alignment with Present Study**
Govindan and Hasanagic (2018)	High cost, lack of awareness, poor regulations	High
Kirchherr et al. (2018)	Resistance to change, lack of clear definitions	High
Kazancoglu et al. (2020)	Supply chain complexity, technology gaps	Moderate
Masi et al. (2017)	Organizational mindset, poor metrics	Moderate
Ghosh (2021 - Indian context)	Weak reverse logistics, financial constraints	High

These comparisons suggest strong alignment, particularly in areas of cost barriers, lack of awareness, and logistical inefficiencies**.** What distinguishes the Indian context is the added complexity arising from informal recycling sectors**,** policy ambiguities, and infrastructure disparities**.**

4.4 Managerial Implications

The prioritization results offer actionable insights for decision-makers across government, industry, and academia:

- For Industry Leaders: Investing in awareness and training can bridge the perception gap among internal stakeholders. Conducting periodic audits and sensitization workshops can gradually overcome change resistance.
- For Policymakers: Targeted subsidies and tax relief for businesses adopting CSCM practices, particularly in reverse logistics and recycling technology, could reduce initial cost burdens.
- For Academia and Researchers: Curricula should incorporate hands-on training in circular economy principles and tools like lifecycle assessment (LCA), material flow analysis (MFA), and sustainable design.
- For Logistics Providers: Collaborating with industries to develop efficient take-back mechanisms and traceable transportation systems using IoT and blockchain can enhance reverse flow integration.

4.5 Strategic Insights for Future Research and Practice

This study highlights the need for a multi-stakeholder, system-oriented approach to overcome CSCM implementation barriers. Indian manufacturers should:

- Develop collaborative ecosystems where by-products and waste materials from one industry serve as raw materials for another (industrial symbiosis).
- Leverage digital technologies to optimize supply chain visibility and circularity—something that is still underutilized despite its recognized benefits.
- Focus on design innovation and sustainable packaging practices that minimize lifecycle waste and facilitate easy disassembly.
- Furthermore, integrating Circular KPIs (e.g., material circularity indicator, reuse rate, energy savings per ton) can provide quantifiable benchmarks for tracking CSCM performance over time.

4.6 Summary of Key Findings

Lack of awareness, high initial costs, and resistance to change emerged as the top three barriers to CSCM adoption. Technological barriers (e.g., poor reverse logistics and inadequate recycling facilities) also hold significant weight. The results align closely with international studies, but India-specific challenges such as the informal recycling sector and low consumer environmental awareness add unique complexity. The use of Fuzzy AHP provided a robust, expert-driven framework to capture uncertainty in subjective judgments, yielding a reliable prioritization of barriers.

5. **CONCLUSION AND POLICY IMPLICATIONS**

5.1 Conclusion

The transition to a circular supply chain model represents a critical pathway for achieving long-term sustainability in Indian manufacturing industries. However, the implementation of CSCM is marred by a multitude of interrelated barriers that span technological, organizational, regulatory, behavioral, and operational domains. This study systematically identified and prioritized the key barriers using the Fuzzy AHP methodology, incorporating expert judgments to address uncertainty and subjectivity in decision-making. The findings revealed that lack of awareness and understanding of CSCM principles, high initial investment costs, and resistance to change are the most critical barriers impeding CSCM adoption. These barriers are foundational in nature and highlight the urgent need for comprehensive stakeholder education, targeted financial interventions, and cultural change within organizations. Additionally, the absence of supporting infrastructure, such as efficient reverse logistics and robust recycling systems, presents significant operational hurdles, especially for SMEs operating with limited resources.

The prioritization of these barriers is consistent with global research, yet uniquely contextualized to India’s socio-economic, policy, and industrial environment. Unlike many developed economies where legislation and public awareness are more mature, Indian industries face compounded challenges due to informal waste management systems, policy ambiguities, fragmented supply chains, and limited access to modern green technologies. The application of the Fuzzy AHP technique in this study has enabled a nuanced understanding of barrier interactions and their relative influence, offering empirical clarity for stakeholders seeking to develop targeted CSCM strategies. By systematically ranking the barriers, this study contributes a robust framework to support managerial decisions, guide policy formulation, and inform future research.

5.2 Policy and Managerial Implications

The insights gained from this study provide several actionable implications for practitioners, policymakers, and academics aiming to accelerate CSCM adoption in India.

5.2.1 For Industry Practitioners

- Awareness Campaigns and Training: Top management and operational staff must be sensitized to the economic and environmental value of circular practices. Industries can initiate in-house training, participate in government-sponsored capacity-building programs, or collaborate with academia for knowledge dissemination.
- Piloting Low-Risk CSCM Models: Businesses can start with small-scale circular initiatives such as product refurbishing, sustainable packaging, or internal recycling to test viability and build confidence before scaling.
- Investing in Digital Infrastructure: Technologies like IoT, AI, blockchain, and digital twins can dramatically improve traceability, waste tracking, and resource optimization. Such investments can lower long-term costs while boosting supply chain efficiency.
- Strengthening Supplier and Customer Integration: Manufacturers should actively engage suppliers and customers to create a closed-loop ecosystem where materials can circulate efficiently. Contracts and incentive systems can encourage partners to align with CSCM objectives.

5.2.2 For Policymakers and Regulatory Authorities

- Subsidies and Incentives: Targeted financial assistance, including tax rebates, low-interest green loans, and capital subsidies for reverse logistics infrastructure and recycling technologies, can reduce the cost burden and de-risk investments.
- Strengthening Regulations: A unified and enforceable regulatory framework that mandates Extended Producer Responsibility (EPR), sustainable procurement, and reverse logistics obligations is essential. These regulations should be complemented with clear compliance mechanisms.
- Promoting Industrial Symbiosis Clusters: The government can encourage the development of industrial parks where waste from one manufacturer serves as input for another. This model, already in use in parts of Europe and East Asia, can be tailored to the Indian context.
- Public-Private Partnerships (PPP): Collaborations between government bodies, industries, and research institutions can accelerate technology adoption, infrastructure development, and circular business models.

5.2.3 For Academic and Research Institutions

- Curriculum Development: Integrating circular economy and sustainable supply chain management into engineering, management, and vocational programs is critical to building a skilled workforce ready for CSCM implementation.
- Cross-Disciplinary Research: There is a growing need for empirical studies that bridge operations management, environmental sciences, and behavioral economics to develop actionable CSCM frameworks.
- Knowledge Hubs and Demonstration Projects: Universities and think tanks can serve as innovation hubs by launching pilot CSCM projects, publishing case studies, and fostering collaborations between students, researchers, and industry.

5.3 Limitations and Future Research Directions

While this study provides a systematic approach to evaluating CSCM barriers in Indian manufacturing, it is not without limitations. The prioritization was based on expert opinions, which, although rigorous, may be subject to contextual or experiential biases. Additionally, the Fuzzy AHP technique captures pairwise comparisons at a snapshot in time and may not account for the dynamic evolution of barrier interactions over longer periods. Future studies may consider the integration of methods like Fuzzy DEMATEL, ISM, or TISM to map inter-barrier relationships and causal linkages more explicitly.

Moreover, sector-specific investigations (e.g., textiles, electronics, pharmaceuticals) may provide deeper insights into industry-tailored CSCM implementation strategies. The exploration of quantitative CSCM performance indicators, consumer perception studies, and digital enablers (e.g., blockchain, smart contracts) also offers fertile ground for future research. Longitudinal studies assessing the impact of recent policy initiatives like India's Circular Economy Mission and EPR mandates can further enrich academic understanding and practical implementation.

The transition to a circular supply chain paradigm is both an environmental necessity and a strategic imperative for Indian manufacturing. This study contributes to the growing body of literature by offering a prioritized roadmap of CSCM adoption barriers using the Fuzzy AHP approach. The results underscore the urgency for coordinated efforts across organizational, technological, financial, and policy dimensions. With robust stakeholder engagement, informed policymaking, and sustained academic involvement, India can accelerate its journey toward a more circular, resilient, and sustainable industrial future.

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