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Computation of Circular Supply Chain Management Enablers Adoption Status in Manufacturing Industries

Vaishali Patel[1], Dr. Pina Bhatt[2], Dr. Jigar Doshi[3]
[1]Research Scholar, Mechanical Engineering Department , Silver Oak University, Ahmedabad - 380061, Gujarat, India, vaishalipatel.rs@silveroakuni.ac.in, 0009-0004-8578-9537
[2]Professor, Mechanical Engineering Department, Silver Oak University, Ahmedabad - 380061, Gujarat, India, pmbhatt15@gmail.com, 0000-0002-2874-5798
[3]Professor, Mechanical Engineering Department, Silver Oak University, Ahmedabad - 380061, Gujarat, India, jigardoshi11@gmail.com, 0000-0002-4998-1263

Study Brief-
The shift from linear to circular supply chains has emerged as a vital strategy for achieving long-term sustainability, resource efficiency, and competitive advantage. However, the adoption of Circular Supply Chain Management (CSCM) practices remains uneven across industries, especially in emerging economies, where practical implementation is hindered by various operational, economic, and cultural challenges. Identifying and prioritising the key enablers that can facilitate the transition to a circular supply chain is therefore crucial for practitioners and policymakers alike.
The present research work specifically analyses and prioritizes the most critical CSCM enablers with the help of the Fuzzy analytical hierarchy process (FAHP) approach, which is a multi-criteria decision-making approach that includes expert inputs and analyses all the factors critically by combining fuzzy set theory to provide the most precise intensity of the selected enablers. The final list of CSCM enablers is obtained through an exhaustive literature review and the opinion of the experts who have specialization in the core supply chain management area, focusing on sustainability. The final obtained list is further categorized into 5 broad groups, which include strategic, technological, organizational, environmental and economic groups. As per the standard fuzzy AHP approach, the expert inputs were collected through pairwise comparison of the main criteria and sub-criteria enablers. Additionally, a consistency check is also carried out for the inputs provided by the expert panel.
The analysis of the multi-criteria decision-making approach reveals that "top management support", "government policy & regulations", and "investment in circular technology" appear to be the most critical enablers that affect the adoption rate of CSCM in manufacturing industries. The current study findings can be treated as key takeaways for the manufacturing firms that are planning to implement circularity in their supply chain and achieve the desired output by maintaining their plan goals and achieving the desired financial performance. This study can be considered as one of the key research works that not only helps in building the theoretical foundation of circularity among the supply chain but also provides the quantitative intensity of the enablers that influence the adoption of circular supply chain management.
Keywords: *circular supply chain management, fuzzy AHP, enablers, manufacturing industries, circular economy*

1. INTRODUCTION

Over the past decade, the manufacturing industries across the globe have started shifting from traditional supply chain models towards sustainable and circularity modules, whether it is part of procurement, in-house storage, the production process, product consumption by customers, or the final disposal. To address the above areas strategically, all the manufacturing industries across the globe have started adopting circular supply chain management practices to sustain themselves in the market in terms of their product brand value as well as their financial performance. This approach has largely contributed to minimizing the hazardous impact on the environment as well as reducing the wastage in the production process (Batista & Francisco, 2025). The concept of circularity primarily got its existence through the circular economy later it got merged with supply chain management in order to push the 6R concept to its next level. By integrating the concept of sustainability within the entire system, the manufacturing organizations have not only mitigated the ecological footprint but they have also started working on the development of a closed-loop system that can be beneficial for the manufacturers as well as the end users (Mani et al., 2025).

Although other manufacturers across the globe have started observing and understanding the benefits of circular supply chain management adoption but still the adoption rate of circular supply chain management is still very low among manufacturing organizations. On the other hand, when the data of emerging economies is observed, the adoption rate is more challenging. Mostly, the developing economies face strong technological setup challenges, where they further observe the unavailability of an implementation framework, and low Awareness of circularity practices among the supply chain, which results in its poor adoption rate. The traditional way of supply chain management adoption primarily focuses on improving efficiency and reducing the manufacturing cost, but the circular supply chain management integrates the sustainability aspect into the system and focuses on creating a closed loop that could focus on creating innovation and strong collaboration among the different stakeholders associated with the entire system. However, the penetration of circular supply chain management within the entire system can be done effectively only if the key enabling factors influencing its adoption are identified which are specifically focused on the manufacturing industry working scenario (Prasad et al., 2025).

It is noticed in the literature that various researchers have worked in the area of circular supply chain management to identify the key enablers that influence its adoption. But it is important to notice that very few of those studies could exactly provide the quantitative value or the intensity of those identified enablers that focus on the adoption of circular supply chain management. Hence, the identification of circular supply chain management enablers is not sufficient to improve the adoption rate. However, if the research is conducted to obtain the computation value of those enablers, then it will directly help the managers and industry practitioners to develop better adoption strategies of circulate supply chain management. It is further important to notice that many of the traditional evaluation methods try to compute the quantitative value of the circular supply chain management, but due to the weakness in the judgments of the experts, the precise value was not obtained. Accordingly, if a structured and analytically linked approach is applied to compute its intensity of adoption, then the final output would be more accurate (Luthra et al., 2025). Hence, to address the above-mentioned gap, the present research work utilizes the fuzzy analytical hierarchy process, in which the traditional HP method is integrated with fuzzy set theory to compute the intensity of circular supply chain management enablers. This approach utilization comparisons of the major and minor criteria factors based on the inputs from the experts.

The present study starts with exploring the existing literature review for preparing the exhaustive list of circular supply chain management enablers that influence its adoption. The circular supply chain management enableds I reported by various researchers in Literature where made into the Excel spreadsheet which was further consulted with the experts and based on their opinion the final list of circular supply chain management enableds was developed. the selected enablers were group among five broad categories that includes strategic, Technological, environmental, economic, and organisation categories.

The main objectives of this research are threefold:

- To identify a comprehensive set of enablers that can facilitate the adoption of CSCM in industrial settings.
- To apply the Fuzzy AHP method to prioritize these enablers based on expert input and fuzzy pairwise comparison.
- To offer practical implications for supply chain managers and policymakers to formulate strategies for effective CSCM implementation.

The novelty of this research lies not only in its application of Fuzzy AHP to CSCM enablers but also in its focus on adoption challenges in emerging economies, where the shift to circular practices is both urgent and complex. By addressing the question of “which enablers matter most,” this study helps fill a crucial gap in the literature and provides a decision-support framework for organizations striving to become more circular and sustainable.

2. LITERATURE REVIEW

Over the past couple of decades, circular supply chain management has gained popularity among different sectors of industry, specifically, the manufacturing organizations have shown a greater interest in adopting this strategy. As this approach has emerged initially from the concept of circular economy, where the circularity of the product and inclusion of the sustainability aspect are primarily focused. This not only increases the product value but also improves the brand and gets its acceptance on a global platform. It further focuses on shifting from traditional operational activities to the sustainability and closed-loop bound activities, which cover all the aspects associated with the different stakeholders of the system.

2.1 Circular Economy and Its Link to Supply Chain Management

The CE concept is fundamentally focuses on regenerating the production process strategies across the closed loop towards its consumption (Singh & Xu, 2025). Supply chains, being central to the movement of materials and products, it should be taken care of from the perspective of all the different associated stakeholders. Several studies have shown that integrating circular economy principles into supply chain has helped in improving the environmental and financial performance (Gupta et al., 2024; Das et al., 2025).

However, the practical implementation of CSCM remains limited due to the inherent complexity of coordinating multiple actors, technological barriers, cost implications, and institutional inertia (Ali & Jayaraman, 2024). Researchers emphasize the need to identify and evaluate key drivers or enablers that can facilitate this transition (Prasad & Singh, 2024).

2.2 Review of CSCM Enablers in Existing Literature

Various studies have identified multiple enablers that support CSCM implementation, often categorized under strategic, technological, organizational, environmental, and economic dimensions.

Strategic Enablers:

Top management support has been widely recognized as a critical enabler for any large-scale sustainability initiative, including CSCM (Chaudhary & Mahajan, 2024). Strategic alignment of sustainability goals with business vision and strong leadership can facilitate resource allocation and policy formation to support circular initiatives (Mani et al. 2024). Cross-functional coordination and long-term commitment also emerge as key strategic enablers (Farooque & Zhang, 2024).

Technological Enablers:

Technological advancement is at the core of CSCM (Das & Kumar, 2023). Technologies such as IoT, Blockchain, AI, and Additive Manufacturing have been identified as critical tools that enhance traceability, product design for recyclability, and real-time monitoring of supply chain activities (Dias et al., 2023). The ability to adopt and integrate digital technologies is often linked to a firm's innovation culture and its openness to circular practices (Mahpour, 2023).

Organizational Enablers:

Organizational culture, employee training, and change management practices are frequently cited enablers in CSCM literature. A culture that promotes environmental awareness and continuous improvement is more likely to embrace circular initiatives (Geissdoerfer et al., 2023). Employee involvement, capacity-building programs, and clear communication channels also strengthen CSCM adoption (Kazancoglu et al., 2022).

Environmental Enablers:

The increasing societal pressure and growing consumer awareness about sustainability have made environmental regulations a significant external enabler. Stringent laws, compliance norms, and regulatory incentives have been shown to nudge organizations toward greener practices (Sharma & Dey, 2022). Additionally, availability of green infrastructure and circular-oriented logistics systems can act as operational enablers.

Economic Enablers:

Economic viability remains a central concern in circular supply chains. Initial investment costs, return on investment, and perceived financial risks are frequently cited barriers (Batista & Francisco, 2022), but also act as enabling factors when economic value is proven. Financial incentives, tax exemptions, access to green finance, and funding from government or private sources can catalyze CSCM adoption (Nair et al., 2022).

List of CSCM Enablers with Categorization

A. Strategic & Managerial Enablers

- Top management commitment and support
- Integration of circularity into business strategy
- Cross-functional collaboration
- Long-term vision for sustainability
- Policy and regulatory compliance awareness
- Supply chain risk management practices

B. Technological Enablers

- Adoption of digital technologies (IoT, Blockchain, AI)

- Product design for modularity and recyclability
- Implementation of cleaner production technologies
- Traceability and monitoring systems
- End-of-life product tracking mechanisms
- Technology upgradation support and infrastructure

C. Organizational Enablers
- Employee training and skill development
- Organizational culture for innovation and learning
- Dedicated sustainability/circularity teams
- Effective internal communication channels
- Performance measurement and KPIs for circularity
- Change management and leadership practices

D. Environmental & External Enablers
- Government incentives and subsidies
- Supportive environmental regulations
- Availability of eco-industrial parks or green infrastructure
- Stakeholder and community engagement
- Public awareness and consumer demand for green products
- Third-party certifications and compliance standards

E. Economic & Market Enablers
- Access to green financing and investment
- Cost savings from resource efficiency
- Revenue opportunities through recovered materials
- Circular business model innovation (e.g., leasing, sharing)
- Market readiness for circular products/services
- Return on investment (ROI) of circular initiatives

2.3 Gaps in the Literature
While existing literature has recognized a wide range of CSCM enablers, a few critical research gaps persist:

- Lack of prioritization: Although many enablers are listed in past studies, there is a lack of consensus on their relative importance, especially across different industry types and national contexts.
- Limited methodological rigor: Many studies use qualitative or survey-based methods without incorporating structured decision-making frameworks.
- Neglect of fuzzy uncertainty: Most quantitative studies fail to account for uncertainty and vagueness in expert assessments, which is common in decision-making around emerging practices like CSCM.
- Sectoral and regional bias: Much of the research is concentrated in developed countries, particularly in the EU. There is a need for more research in emerging economies like India, where industrial growth is high, but circular implementation remains nascent.

2.4 Role of Multi-Criteria Decision-Making (MCDM) Methods
MCDM techniques are increasingly used in sustainability-related decision-making due to their ability to handle multiple conflicting criteria. Studies have used AHP, TOPSIS, DEMATEL, and ISM to analyze barriers and enablers in sustainable supply chains (Mangla et al., 2021). However, these methods often rely on crisp values and may not reflect the ambiguity involved in expert opinions.

To address this issue, Fuzzy AHP has been proposed as a more robust alternative that integrates fuzzy logic with traditional AHP. It accommodates linguistic variables, enabling experts to express preferences with greater flexibility (Jabbour et al., 2021). The method has been applied in domains such as green supplier selection (Rahman & Kim, 2019), sustainable manufacturing (Farooque et al., 2019), and lean implementation (Goyal et al., 2019), but remains underexplored in the context of CSCM enabler prioritization.

2.5 Justification for Current Study

The need to transition to a circular supply chain is more pressing than ever due to escalating environmental concerns and resource depletion. However, effective adoption hinges on identifying and acting upon the most influential enablers. Given the multi-dimensional and uncertain nature of this problem, Fuzzy AHP offers a compelling method for prioritizing enablers in a structured, reliable manner.

This study contributes to the literature by:

- Synthesizing a comprehensive list of CSCM enablers relevant to manufacturing industries in emerging economies.
- Applying Fuzzy AHP to derive the relative importance of these enablers, thereby aiding managerial decision-making.
- Bridging methodological gaps by combining expert insights with fuzzy logic to enhance the robustness of evaluation.

The insights gained from this analysis are expected to assist policymakers, sustainability strategists, and supply chain professionals in focusing their efforts on the most impactful areas for promoting CSCM adoption.

3. RESEARCH METHODOLOGY

To effectively evaluate and prioritise the critical enablers of Circular Supply Chain Management (CSCM), this study adopts a Fuzzy Analytic Hierarchy Process (Fuzzy AHP). This method enables the incorporation of expert judgment under uncertainty and addresses the limitations of conventional AHP by integrating fuzzy logic, thereby handling vagueness and imprecision in linguistic assessments.

The research methodology consists of the following sequential steps:

3.1 Identification of CSCM Enablers

A systematic literature review was conducted to identify key enablers that facilitate the implementation of CSCM practices, particularly in the context of emerging economies. Research articles, review papers, and industry reports from 2015 to 2024 were reviewed. This initial list of enablers was then validated and refined through expert consultations with supply chain professionals, sustainability consultants, and academic researchers. A total of 30 enablers were finalised and classified into five main categories:

Strategic & Managerial, Technological, Organizational, Environmental & External, Economic & Market

3.2 Structuring the AHP Hierarchy

The hierarchical model of this study comprises three levels:
Level 1: The main objective – Prioritisation of CSCM Enablers
Level 2: Five criteria groups (enabler categories)
Level 3: Thirty individual CSCM enablers
This structure provides a clear view of how various enablers contribute to CSCM adoption.

3.3 Selection of Experts and Data Collection

A panel of 15 domain experts was selected using purposive sampling. The experts were chosen based on their experience in circular economy, sustainable supply chain, manufacturing, or environmental policy. Each expert had a minimum of 10 years of professional experience or had published peer-reviewed research on related topics.

Data was collected through structured questionnaires designed to perform pairwise comparisons among enablers and their respective categories. Experts used linguistic scales (e.g., equally important, moderately more important, strongly more important) to express their preferences.

3.4 Fuzzy AHP: Methodological Framework

The Fuzzy AHP approach used in this study follows the Chang's Extent Analysis Method, which is suitable for multi-criteria decision-making. The key steps include:
-Form the decision group
The initial step comprises of formation of decision group which includes SLSS project managers, representatives from Information technology department, Six Sigma Belt experts and several senior executives involved in decision making process.
-Enumerate main and sub criteria to build a hierarchical structure

While undergoing this step, all the potential barriers are identified from comprehensive literature review conducted across peer reviewed journals and finalizing them through discussion with expert panel formed in previous step. Hence these selected SLSS barriers are inserted in execution process for their prioritization. At the beginning the main problem is disintegrated into a hierarchical structure including main aim, main criteria and sub criteria respectively.

-Specify the Triangular fuzzy number scale adopted for forming the pairwise comparison matrix

In the present study triangular fuzzy number scale $\tilde{1}$ to $\tilde{9}$ are employed to enhance the solution of the proposed problem. Table 1 shows scale of relative importance utilized in pairwise comparison matrix. Basically this scale gives flexibility to overcome biasness and qualitative judgments made by human personals that leads deviation from the precise solution. The included five TFN's ($\tilde{1},\tilde{3},\tilde{5}, \tilde{7}, \tilde{9}$) are also specified with their respective membership functions. For linguistic values of criteria

-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.

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.

-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.

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.

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

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

-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.

-Prioritize each criteria according to final weight obtained

Lastly the final weights for each criteria are obtained by multiplying the major criteria weight with sub criteria weight to obtain the final weight of the corresponding criteria. Once the final weight of all the criterias are obtained then all the criteria are prioritized accordingly.

4. RESULTS AND DISCUSSION

This section presents the outcomes derived from applying the Fuzzy AHP to prioritize enablers of CSCM. The analysis is based on expert input collected through pairwise comparisons, defuzzification of weights, and normalization to derive final priorities. The results are discussed both quantitatively and in comparison, with existing literature to draw insights relevant for improving CSCM adoption in emerging economies.

4.1 Normalized Weights of Main Enabler Categories

The fuzzy AHP analysis revealed the following normalized weights for the five primary enabler categories as shown in Table 1:

Table-1- Main criteria weight of circular supply chain management enablers

Category	Normalized Weight
Strategic & Managerial	0.261
Technological	0.221
Economic & Market	0.192
Organizational	0.174

Category	Normalized Weight
Environmental & External	0.152

Interpretation:
Strategic & Managerial enablers received the highest weight, suggesting that top-level commitment and integrated circular strategies are fundamental to CSCM adoption. This aligns with the argument by Mangla et al. (2018), who emphasized strategic orientation as a catalyst for circular practices. Technological factors followed closely, underscoring the role of digital innovation and product redesign.

4.2 Final Ranking of CSCM Enablers
Based on the defuzzified values and normalization, the top 10 ranked enablers are presented below in Table 2:

Table-2- Weight of top 10 most critical circular supply chain management enablers

Rank	Enabler	Priority Weight
1	Top management commitment and support	0.10128
2	Adoption of digital technologies (IoT, Blockchain, AI)	0.07523
3	Employee training and skill development	0.06342
4	Product design for modularity and recyclability	0.06157
5	Integration of circularity into business strategy	0.05799
6	Access to green financing and investment	0.04371
7	Cross-functional collaboration	0.04036
8	Cost savings from resource efficiency	0.03698
9	Organizational culture for innovation and learning	0.03684
10	Long-term vision for sustainability	0.03595

Insights:
Top management support emerged as the most critical enabler, reinforcing the centrality of leadership in driving circular initiatives. The significance of digital technologies and product design points to the operational complexity of implementing CSCM, as highlighted in the work of Nasir et al. (2023). Economic and policy drivers, such as subsidies and green business models, also ranked high, confirming their role in overcoming financial and regulatory barriers.

The FAHP-based analysis produced a structured prioritization of the 30 CSCM enablers across five categories: Strategic & Managerial, Technological, Economic & Market, Organizational, and Environmental & External. Global weights were computed by multiplying local weights within each category by the corresponding category weights, ensuring that the sum of all enablers equaled unity. The results reveal that “Top management commitment and support” (Global Weight: 0.1013) emerged as the most critical enabler, followed by “Adoption of digital technologies (IoT, Blockchain, AI)” (0.0752) and “Employee training and skill development” (0.0634). These enablers reflect the leadership, technological, and workforce capabilities necessary to drive circularity adoption in manufacturing. Other high-ranking enablers include “Product design for modularity and recyclability” (0.0616) and “Integration of circularity into business strategy” (0.0580), underscoring the strategic integration of design and policy into operational practices.

At the lower end of the ranking, enablers such as “Supply chain risk management practices” (0.0095), “Change management and leadership practices” (0.0130), and “Performance measurement and KPIs for circularity” (0.0147) were assigned comparatively lower global weights. While less influential in the current context, these enablers still contribute to long-term CSCM sustainability and should not be overlooked.

The FAHP results highlight the dominance of leadership, technological readiness, and human capital in enabling effective circular supply chain management in manufacturing industries. The top-ranked enabler, Top management commitment and support, not only carries the highest local weight within its category (0.3881) but also the highest global weight across all enablers (0.1013). This emphasizes that leadership commitment is indispensable for mobilizing resources, fostering a culture of sustainability, and ensuring alignment between corporate vision and circular economy objectives.

The strong positioning of Adoption of digital technologies (IoT, Blockchain, AI) (0.0752) signals the growing reliance on Industry 4.0 solutions to enhance traceability, improve material flows, and enable predictive decision-making. Similarly, Employee training and skill development (0.0634) reflects the crucial role of upskilling the workforce to handle new technologies, implement innovative processes, and support organizational transformation toward circularity.

From the product design perspective, Product design for modularity and recyclability (0.0616) stands out as a pivotal technological enabler, enabling easier disassembly, reuse, and recycling. Likewise, Integration of circularity into business strategy (0.0580) reinforces the importance of embedding circular principles into the strategic core of the organization rather than treating them as peripheral initiatives.

Interestingly, while Economic & Market enablers such as Access to green financing and investment (0.0437) and Cost savings from resource efficiency (0.0370) rank moderately high, they are still secondary to leadership, technological, and human capital factors. This suggests that financial considerations, though important, may be contingent on the presence of robust strategic and operational foundations.

Lower-ranking enablers like Supply chain risk management practices (0.0095) and Performance measurement and KPIs for circularity (0.0147) indicate potential gaps in operational risk preparedness and metrics standardization for circular initiatives. These areas may warrant targeted interventions in future roadmaps, as improved risk mitigation and performance tracking could strengthen the long-term resilience of CSCM adoption.

4.3 Mid- and Low-Priority Enablers

While some enablers such as stakeholder engagement, traceability systems, and third-party certifications were found to be important, they ranked lower due to indirect or supporting roles. For instance as shown in Table 3:

Table-3- Weight of mid and low priority circular supply chain management enablers

Rank	Enabler	Weight
14	Dedicated sustainability/circularity teams	0.02889
15	Government incentives and subsidies	0.02812
29	Change management and leadership practices	0.01303
30	Supply chain risk management practices	0.00946

These findings suggest that while supportive structures and policies matter, the actual initiation and implementation rely heavily on strategic, technological, and market-based drivers. The results are in alignment with past studies. For example, Dey et al. (2021) stressed the importance of strategic alignment and leadership in overcoming implementation resistance. Kazancoglu et al. (2018) observed that technology plays a key enabling role, especially for resource recovery and monitoring in circular supply chains. Ghisellini et al. (2018) and Agyemang et al. (2019) highlighted policy and customer-side enablers, which were echoed in this study but ranked moderately. Decision-makers should prioritize leadership commitment, strategic integration, and digital transformation to accelerate CSCM. Policy-makers can support adoption by offering clear regulatory incentives and promoting eco-industrial infrastructure. Industry practitioners must invest in modular product design and employee training to operationalize circular strategies.

5. Conclusion and Future Research Directions

This study set out to address a pressing need in today's supply chain landscape: the effective adoption of CSCM. Using a F-AHP, we identified, categorized, and prioritized a set of enablers that are instrumental in advancing circularity across industries. The fuzzy AHP method was particularly valuable in navigating the inherent uncertainty and subjectivity involved in expert judgments, resulting in a more robust and defensible prioritization.

Our findings reveal that strategic and managerial enablers—particularly top management commitment and alignment with circular business strategy—carry the highest influence in promoting CSCM. This insight reaffirms the pivotal role of leadership vision in driving systemic change. Technological enablers, especially the integration of digital tools and data analytics, also emerged as critical components, showcasing the increasing reliance on Industry 4.0 capabilities to facilitate circular operations. While economic, organizational, and environmental factors are certainly relevant, their impact appears more supportive than dominant—indicating that circular transformation must be strategically led and digitally enabled.

The findings of this study carry significant implications for multiple stakeholder groups engaged in the adoption and promotion of CSCM in manufacturing industries. The prioritization of enablers using the Fuzzy Analytic Hierarchy Process offers targeted insights that can guide strategic planning, resource allocation, and policy design. Since Strategic & Managerial enablers ranked highest, managers should prioritize securing top management commitment, defining a long-term vision, and fostering cross-functional collaboration. Even though organizational enablers ranked lower than strategic and technological factors, fostering a culture supportive of sustainability, continuous learning, and change readiness remains a vital long-term success factor. With technological enablers emerging as the second most critical category, managers should accelerate the adoption of Industry 4.0 tools such as IoT, AI-driven analytics, and digital twins to enable efficient resource recovery, waste reduction, and process monitoring. The use of Fuzzy AHP offers a robust decision-support framework that accounts for uncertainty in expert judgment, making it adaptable to other sustainability domains.

The prioritized enablers can be adapted into industry-specific guidelines (e.g., automotive, electronics, textiles) to tailor adoption strategies. Establishing clear, enforceable CSCM standards aligned with environmental laws will help reduce compliance uncertainty for businesses. Policymakers can foster industrial symbiosis by creating platforms for resource sharing, joint innovation, and knowledge exchange across industries. Given the high ranking of strategic and technological enablers, policies should incentivize R&D in circular technologies, subsidize the adoption of advanced manufacturing tools, and support management training in sustainability. Practitioners can combine these results with other Multi-Criteria Decision-Making (MCDM) tools such as BWM, DEMATEL, or CoCoSo to explore interdependencies and performance linkages.
For practitioners, these results offer a clear roadmap by a clear focus on the initial investments and change management efforts on high-priority enablers such as leadership involvement, circular thinking at the strategic level, and technology deployment. Government bodies and policymakers can use this framework to design incentive mechanisms, training initiatives, and regulatory policies that support these key drivers.

Like any analytical approach, this study is not without limitations. The enabler set was derived from literature and validated by a select group of domain experts. Broader industrial validation across different geographies and sectors could improve generalizability. Also, while fuzzy AHP accounts for subjectivity, it remains a comparative method and does not account for the interdependencies between factors.

Future Research Directions
Several avenues remain open for exploration:

- Fuzzy DEMATEL or Interpretive Structural Modelling (ISM) could be used in tandem with AHP to map causal relationships among enablers.
- The framework could be applied to specific sectors—like automotive, electronics, or fast-moving consumer goods—to uncover domain-specific priorities.
- Future studies could include inhibitors (barriers) in parallel to enablers to provide a dual-view for CSCM adoption.
- Integration of this model with quantitative performance metrics (e.g., carbon reduction, cost savings) could make the outcomes more actionable.

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