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Sustainable Supply Chain Management In Indian Construction Projects: Environmental Challenges, Innovations And Policy Recommendations

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Abstract
This study presents a critical examination of Sustainable Supply Chain Management (SSCM) practices in the Indian construction sector, with a specific focus on environmental performance, adoption barriers, and policy implications. Drawing on data from 487 structured survey responses and 20 expert interviews, the paper identifies key drivers and inhibitors of sustainability across different project types residential, commercial, industrial, and infrastructure. The findings reveal that while infrastructure projects show stronger integration of digital tools such as Building Information Modelling (BIM) and IoT-enabled monitoring systems, most residential and SME-led projects continue to rely on traditional, non-sustainable methods. Major challenges include the lack of structured green procurement practices, poor vendor compliance with environmental standards, and limited use of formal risk assessment frameworks. Sectoral differences are also prominent, with private organizations demonstrating more openness to innovation and sustainability than their public-sector counterparts. In response to these gaps, the study proposes targeted policy measures, including the creation of centralized digital portals for compliance tracking, green vendor certification frameworks, and training programs focused on environmental risk management. These strategies aim to foster a more resilient and environmentally responsible construction supply chain ecosystem in India, aligning industry practices with national and global sustainability goals.

Keywords: *Sustainable supply chain management (SSCM), Green procurement, Environmental compliance, Low-carbon logistics, Policy alignment*

1. INTRODUCTION

The construction industry plays a central role in India's economic development, contributing nearly 8–9% to the national GDP while providing employment across a wide range of skill levels. However, despite its scale and significance, the sector is among the largest contributors to environmental degradation, accounting for substantial emissions, resource consumption, and construction waste. These environmental pressures have placed sustainable supply chain management (SSCM) under increasing scrutiny, particularly in the context of India's commitments to global climate agreements and the United Nations Sustainable Development Goals (SDGs) [1-6].

Historically, supply chain practices in construction have focused on cost efficiency and project timelines, often neglecting the environmental implications of procurement, logistics, and material use. The fragmented nature of construction supply chains—spanning multiple stakeholders including contractors, suppliers, consultants, and clients—has compounded these challenges, resulting in operational inefficiencies and missed sustainability opportunities [7]. Integrated SSCM frameworks that incorporate digital coordination, environmental risk planning, and life-cycle thinking are now seen as essential for minimizing the sector's ecological footprint [8]. Tools such as Building Information Modelling (BIM), cloud-based Enterprise Resource Planning (ERP), and the Internet of Things (IoT) offer significant

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potential for improving transparency, reducing waste, and supporting environmentally responsible decision-making [9-10].

Despite these technological advancements, SSCM adoption in India remains uneven. While infrastructure projects led by government or large private consortia tend to demonstrate better integration of sustainable practices, smaller residential and commercial projects often run by SMEs lag significantly behind. The reasons range from financial constraints and low digital literacy to a lack of incentives or regulatory pressure [11]. Moreover, sustainability is often perceived as a compliance burden rather than a value-generating opportunity, limiting its adoption at the firm level [12].

Recent literature has highlighted growing interest in green supply chain principles, but significant gaps remain in empirical validation, especially in the Indian context. While tools such as green procurement protocols, carbon accounting, and environmental risk mapping have been widely discussed, their practical application in Indian construction remains limited and largely anecdotal [13]. Cultural resistance, policy inconsistency across states, and limited stakeholder coordination further complicate the path toward SSCM implementation [14].

This study seeks to bridge these knowledge and practice gaps by conducting a mixed-methods investigation of SSCM adoption across different types of construction projects in India. The research evaluates key performance indicators related to digital adoption, green procurement, regulatory compliance, and organizational readiness. Through both quantitative survey data and qualitative interviews, the study offers actionable insights into sectoral disparities, enabling factors, and policy levers that could drive large-scale SSCM transformation. Ultimately, this paper contributes to the growing body of sustainability literature by highlighting a path toward more environmentally responsible construction practices in India.

2. LITERATURE REVIEW

Sustainable supply chain management (SSCM) has emerged as a vital framework for mitigating the environmental impact of construction activities. Rooted in the principles of the triple bottom line environmental, social, and economic sustainability SSCM goes beyond conventional efficiency goals to integrate environmental accountability into procurement, logistics, and supplier engagement [15]. In the construction sector, where supply chains are often fragmented and project-based, embedding sustainability is particularly challenging. However, the sector's considerable carbon footprint, energy intensity, and waste generation make it a natural focus area for green transformation [16].

Earlier studies on construction supply chains focused primarily on cost and schedule control, with limited attention to ecological outcomes. Over time, the growing urgency of climate change and the influence of international policy instruments have pushed sustainability into the mainstream of construction discourse [17]. As a result, tools like Building Information Modelling (BIM), life-cycle assessment (LCA), and green procurement protocols have gained traction. BIM, for instance, enables pre-construction modeling that minimizes waste, while IoT devices can track environmental variables like fuel consumption and air quality during material transport [18 - 20].

Despite these advancements, practical implementation of SSCM remains limited in many parts of the world, and particularly in India. A significant portion of Indian construction firms especially SMEs face barriers such as lack of awareness, high initial investment costs, and limited access to green-certified suppliers [21]. Regulatory fragmentation, inconsistent environmental approval processes, and weak enforcement further complicate efforts to adopt sustainability practices. Even where green building certifications exist, their integration into routine supply chain decisions is rare [22 -23].

Several frameworks, including the SCOR model and the House of Risk (HoR), have been used internationally to assess environmental and supply chain risks. Yet their uptake in Indian construction is limited, both in academic studies and practical application [24]. Moreover, the emphasis tends to remain on end-of-pipe solutions such as waste recycling rather than upstream interventions like eco-design, local sourcing, or vendor capacity building [25 – 26].

Emerging research points to the growing relevance of digital tools in driving SSCM. Cloud-based procurement systems, AI-enabled forecasting, and real-time carbon tracking are becoming more accessible and affordable. These tools are helping firms move from reactive compliance toward proactive environmental performance monitoring [27]. At the same time, attention is increasingly being paid to the

social dimensions of sustainability, including labor rights, diversity, and stakeholder inclusion areas that remain underexplored in the Indian context [28].

Despite a rising interest in SSCM, the body of empirical research in India remains limited in scope. Most studies are either conceptual or based on isolated case analyses. There is a clear need for broader, data-driven investigations that explore SSCM adoption across multiple sectors and regions. This study responds to that gap by presenting quantitative and qualitative evidence from a diverse sample of construction professionals, aiming to offer a well-rounded view of how SSCM is practiced and how it could be improved in one of the world's fastest-growing construction markets.

3. METHODOLOGY

This research adopts a mixed-methods approach to investigate the implementation and effectiveness of sustainable supply chain management (SSCM) practices in Indian construction projects. By integrating both quantitative and qualitative methods, the study captures a multidimensional perspective on environmental performance, organizational capability, and sectoral challenges. The overall research design emphasizes triangulation, thereby enhancing the reliability and depth of findings [29].

A convergent research design was selected, combining structured survey data with semi-structured interviews. The survey instrument was designed to capture quantitative indicators across key SSCM domains such as sustainability practices, digital tool adoption, green procurement strategies, environmental risk management, and regulatory compliance. A total of 500 questionnaires were distributed, of which 487 valid responses were received, yielding a high response rate of 97.4%. Respondents represented a mix of sectors including residential, commercial, industrial, and infrastructure projects and were primarily drawn from roles related to procurement, engineering, and project management. Table 1 indicates the important data's included in questionnaires.

Table 1: Key SCM Practices Identified in the Indian Construction Sector

S.NO	SUPPLY CHAIN PRACTICES
SCP1	Searching for new ways to integrate SCM activities
SCP2	Improving the integration of activities across the SC
SCP3	Reducing response time across the SC
SCP4	Establishing more frequent contact with SC members.
SCP5	Cooperation throughout the SC.
SCP6	Clearer expectations by all parties in the SC
SCP7	Creating a compatible information System
SCP8	Use of informal information sharing agreement.
SCP9	Use of formal information sharing agreement.
SCP10	Creating a greater level of trust among SC members
SCP11	Extending SC beyond immediate Suppliers/Customers.
SCP12	Requiring suppliers to locate closer to your firms
SCP13	Use of a third-party SCM specialist in projects
SCP14	Increasing your firm's JIT capability

SCP15	Aiding Subcontractors/Suppliers to increase their JIT capacity.
SCP16	Participating in the sourcing decisions.

To complement the survey data, 20 in-depth interviews were conducted with stakeholders across the supply chain, including project managers, consultants, government engineers, and private developers. The interviews were designed to elicit rich, context-specific insights into organizational behavior, regulatory challenges, vendor engagement, and environmental priorities. These qualitative responses provided valuable context to interpret the survey data and highlight nuances that could not be captured quantitatively.

A purposive sampling technique was employed to ensure that participants had relevant experience in supply chain and sustainability functions. The sampling strategy prioritized geographical and sectoral diversity, ensuring that insights reflected a broad spectrum of project sizes, funding models, and organizational cultures.

Data analysis was conducted using both statistical and thematic tools. Descriptive statistics, including frequency distributions, mean scores, and standard deviations, were calculated using SPSS v24. Exploratory Factor Analysis (EFA) was used to identify latent dimensions within SSCM practices, and multiple regression analysis was conducted to evaluate the influence of factors such as experience, project type, and organizational affiliation on SSCM outcomes [30]. For qualitative data, transcripts were coded and analyzed thematically using NVivo software. The analysis focused on recurring themes such as environmental awareness, policy fragmentation, digital tool usage, and vendor readiness.

Ethical standards were upheld throughout the research process. Informed consent was obtained from all participants, and their confidentiality was protected through anonymization of personal identifiers. Participation was entirely voluntary, and respondents were informed of their right to withdraw at any stage [31]. The study's limitations include its regional concentration in Southern and Western India, and its reliance on self-reported data, which may be subject to bias. Nonetheless, the combination of robust sampling and multi-layered analysis provides a strong foundation for the insights generated.

4. RESULTS AND DISCUSSION

This section presents an integrated analysis of the quantitative survey results and qualitative interview insights to evaluate the maturity and effectiveness of sustainable supply chain management (SSCM) practices in the Indian construction sector. The findings are interpreted with a strong emphasis on environmental performance, particularly in areas such as green procurement, digital technology integration, risk governance, and policy implementation. The survey captured responses from 487 professionals, while 20 expert interviews provided contextual depth, focusing on project-level sustainability experiences and organizational readiness.

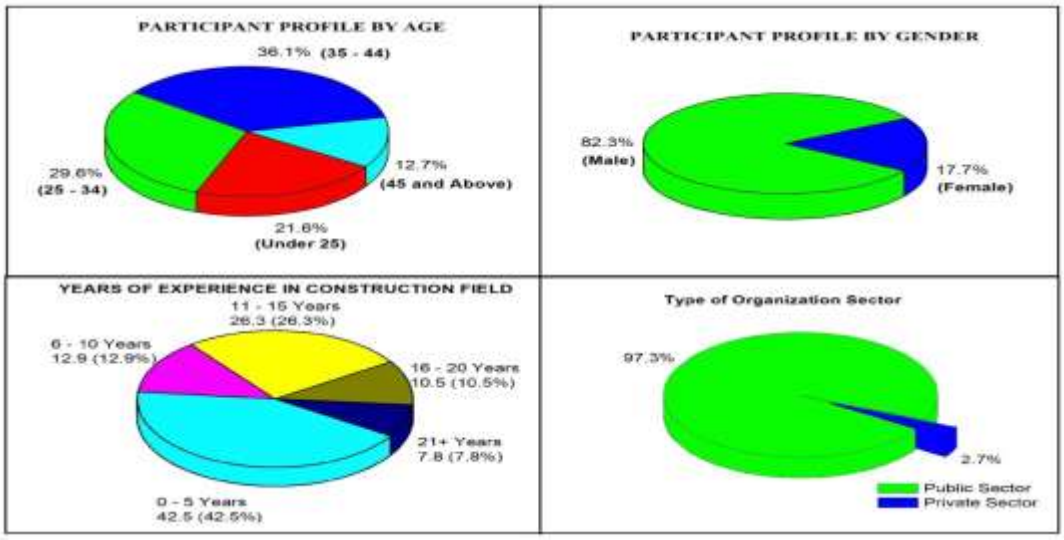

Figure 1: Participant Profile by Age, Gender, Experience and Sector

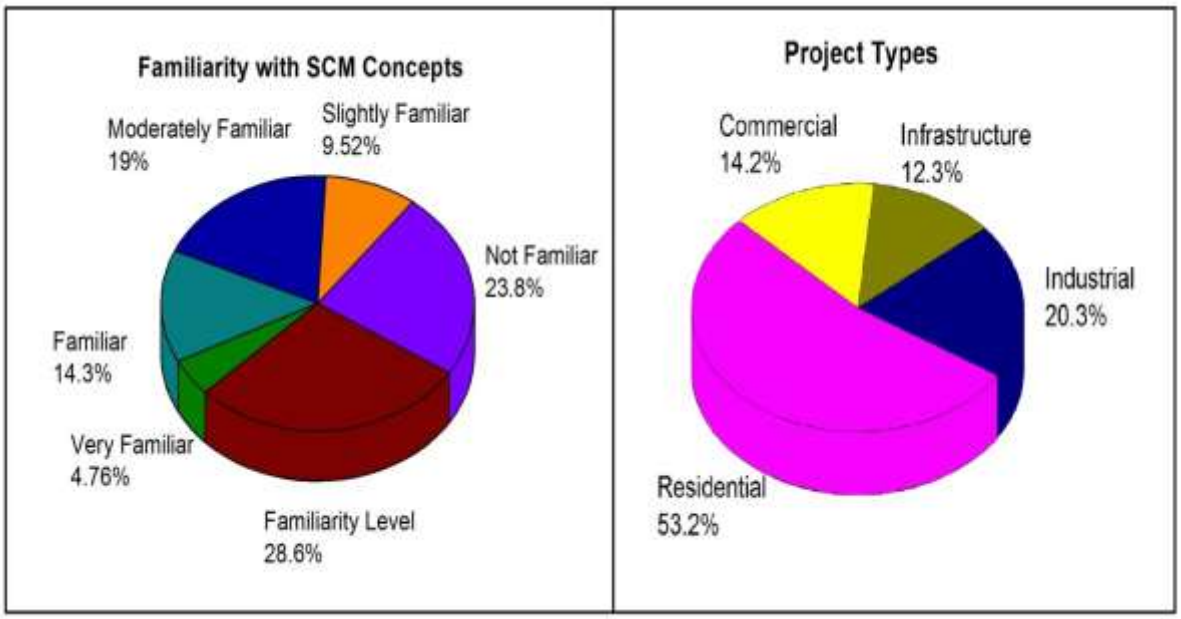

Figure 2: Familiarity with SCM Concepts among Respondents

The demographic data, illustrated in Figure 1, indicate that most respondents were mid-career professionals aged between 35 and 44, engaged in procurement, engineering, and project management. However, Figure 2 reveals that only 4.8% of these professionals considered themselves very familiar with SSCM concepts, while nearly 24% reported limited or no familiarity. This awareness gap underscores a critical barrier to effective environmental decision-making across the construction lifecycle, particularly in procurement and vendor evaluation processes where sustainability considerations should ideally play a central role [32]. Further, this observation, showing that only a small proportion of participants were comfortable with core SSCM terminology such as carbon accounting, life-cycle assessment, and green logistics.

Table 2: Mean Scores of Major SCM Components

SCM Component	Mean Score	Standard Deviation (SD)
Inventory Management	15.77	2.68
Risk Management	14.53	3.76
Technology & Innovation	6.64	1.74
Sustainability Practices	6.68	1.79
Performance Measurement	9.96	1.94
Demand Forecasting	7.03	1.61

A deeper component analysis, shown in Table 2, highlights that while practices like inventory management and risk oversight scored relatively high in implementation, sustainability practices and technological innovation lagged behind. Specifically, sustainability practices recorded a mean score of 6.68, and technology and innovation 6.64, indicating a weak environmental orientation in daily operations. These findings suggest that although Indian construction firms are increasingly aware of SCM tools, their use is still rooted in traditional efficiency metrics rather than ecological performance. Figure 3 further illustrates that female professionals, although underrepresented, consistently rated environmental indicators higher than their male counterparts, aligning with broader literature that links gender diversity with greater organizational sensitivity to sustainability goals [33].

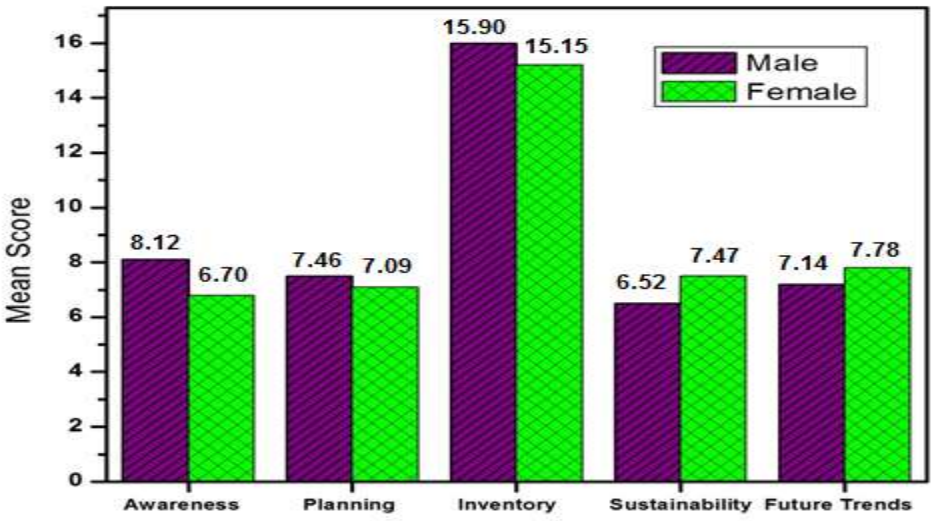

Figure 3: Gender-Based SCM Scores

Table 3: Familiarity Levels with SCM Concepts (n = 487)

Familiarity Level	Frequency	Percentage
Very Familiar	66	13.6%
Familiar	151	31.0%
Moderately Familiar	153	31.4%
Slightly Familiar	87	17.8%
Not Familiar	30	6.2%

A comparison across project types reveals considerable differences in SSCM adoption. Infrastructure and industrial projects consistently outperformed residential and commercial segments, as seen in Table 4. These differences can be attributed to centralized procurement frameworks, regulatory oversight, and higher budgets, which typically characterize public infrastructure development. In contrast, residential projects especially those led by small and medium enterprises often operate without formal SSCM protocols or sustainability benchmarks, resulting in fragmented vendor practices and low environmental compliance. These disparities are further highlighted in the radar chart presented in Figure 4, which maps SSCM maturity across four dimensions: technology adoption, vendor integration, regulatory compliance, and risk responsiveness. Infrastructure projects cluster closest to the "mature" SSCM quadrant, indicating relatively stronger integration of sustainability strategies.

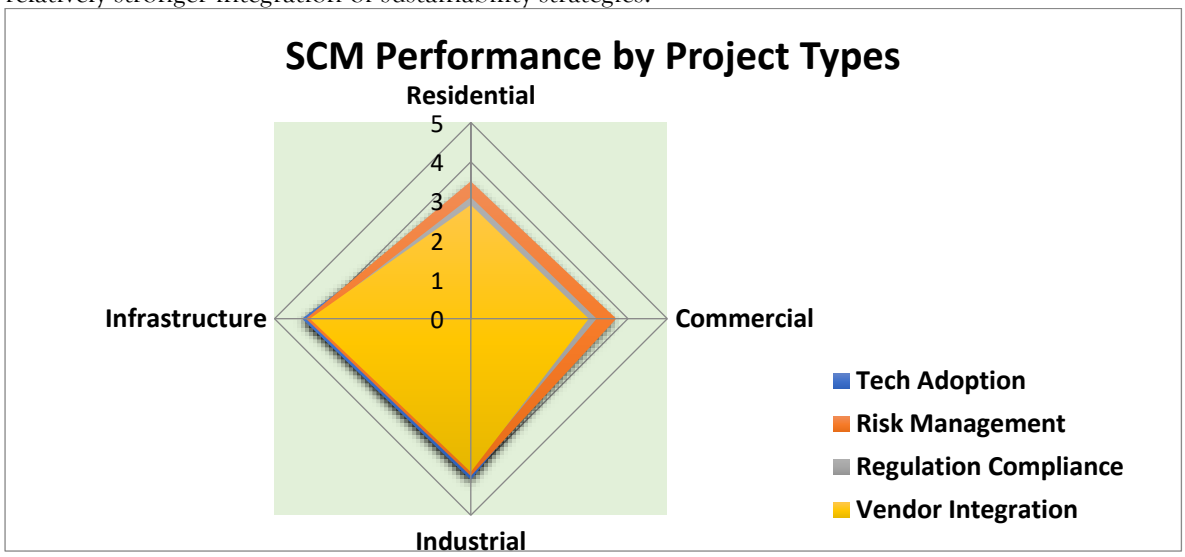

Figure 4: Radar Chart – SCM Maturity Across Project Types

Table 4: Comparison of SCM Attributes Across Project Types

SCM Attribute	Residential	Infrastructure	F-value	p-value
Vendor Reliability	11.39 (SD 3.36)	12.95 (SD 3.26)	6.38	.001
Technological Adoption	10.98 (SD 3.27)	13.09 (SD 3.38)	10.86	.001

Table 5: SCM Objectives by Project Type

Project Type	Mean Score	Std. Deviation
Residential	48.75	15.31
Commercial	44.75	19.03
Industrial	56.70	11.01
Infrastructure	60.14	17.02

Despite the growing consensus on the importance of risk planning, the study found that only 24% of respondents use structured risk tools such as FMEA or House of Risk models. Yet, 70% acknowledged that SCM practices reduce material delays and procurement errors, which could indirectly reduce waste and emissions. The absence of formal risk assessment frameworks poses a threat to project sustainability, as many construction activities still respond to issues reactively rather than through proactive environmental risk mitigation [34]. Interview responses echoed this concern, with many professionals reporting a lack of awareness or training in environmental risk tools. Notably, 61% of respondents indicated a need for SSCM and environmental risk training, highlighting a critical opportunity for industry-wide capacity building.

Table 6: Sectoral Differences in SCM Practice Scores

SCM Component	Public Sector Mean	Private Sector Mean
Sustainability Practices	5.15	6.73
Technology & Innovation	5.55	6.95
Risk Management	12.45	14.88
Vendor Integration	13.62	15.20
Regulatory Compliance	11.89	13.02

Figure 5 presents a heatmap comparing sector-specific SSCM challenges. Residential and commercial projects exhibited higher frequencies of digital underutilization, policy non-compliance, and vendor unreliability, whereas infrastructure projects, while more complex, benefited from institutional systems and formal protocols. These findings were reinforced by several interviewees who emphasized the bureaucratic efficiency in government-led projects despite their procedural rigidity. Table 7 summarizes SSCM maturity scores by project type, where infrastructure projects achieved a mean score of 50.69, compared to less than 40 for residential and commercial projects. This performance gap points to a need for differentiated intervention strategies tailored to sectoral maturity levels.

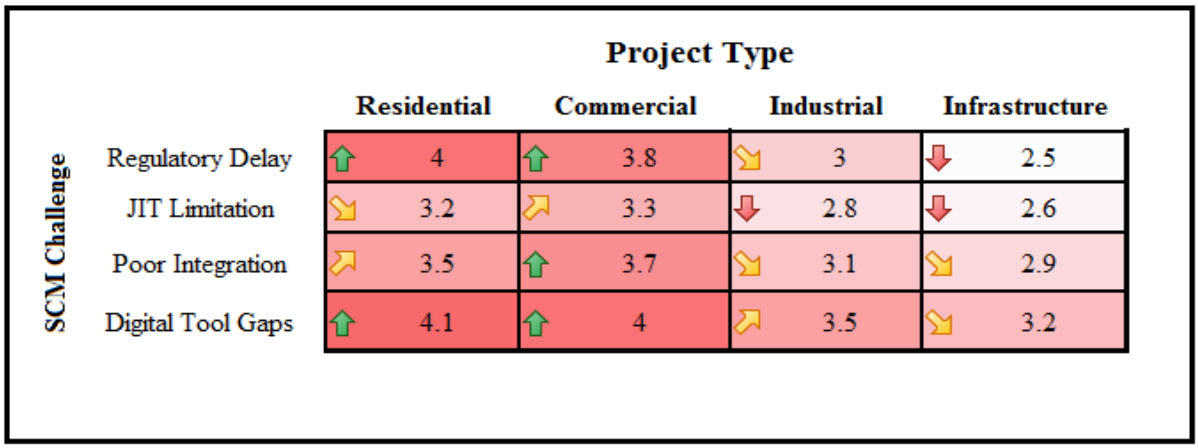

Figure 5: Heatmap – SCM Challenges by Project Type

Table 7: Mean SCM Maturity Scores by Project Type

Project Type	Mean Score
Residential	39.64
Commercial	38.75
Industrial	49.55
Infrastructure	50.69

Experience was found to be a strong predictor of SSCM effectiveness, as illustrated by the regression model in Figure 6. Professionals with longer tenure, especially in infrastructure development, demonstrated higher familiarity with sustainability tools and protocols. Interview insights revealed that these individuals often play critical roles in championing SSCM within their organizations. Public sector professionals, exposed to government-mandated frameworks, also showed relatively higher SSCM adoption rates, particularly in environmental documentation and vendor oversight.

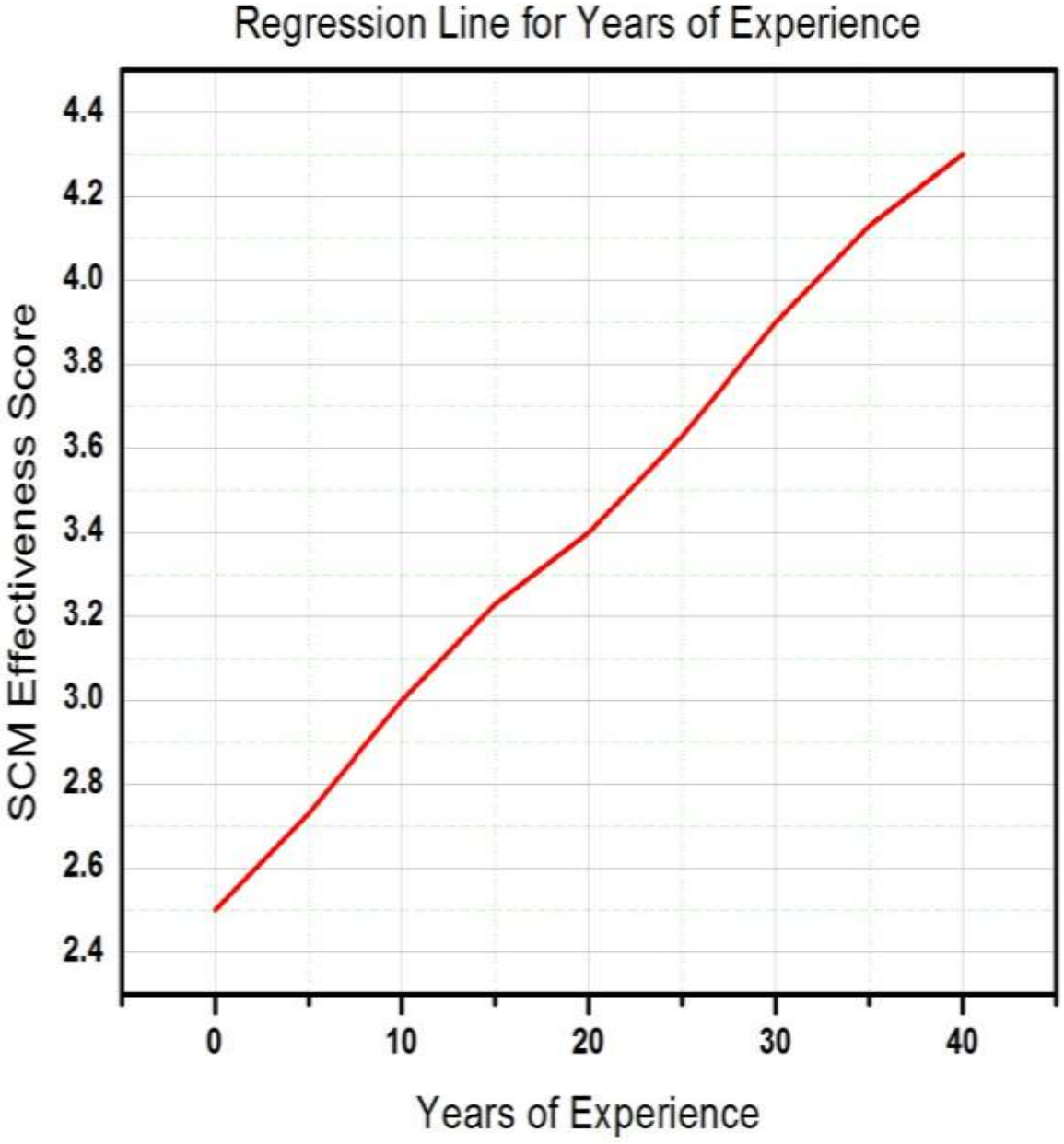

Figure 5: Regression – Experience vs SCM Effectiveness

Finally, a recurring theme from the interviews was the lack of formal SSCM roles within organizations. Over 60% of respondents reported no designated sustainability officer or supply chain strategist. Many

firms continue to treat supply chain functions as operational support tasks, with little to no emphasis on environmental performance. This cultural and organizational inertia severely limits the implementation of structured green procurement, vendor audits, or real-time tracking of environmental KPIs. In summary, while pockets of maturity exist particularly in infrastructure the broader Indian construction industry remains underprepared for systemic SSCM transformation.

5. STRATEGIC RECOMMENDATIONS

The results of this study indicate that while SSCM practices are gaining attention in Indian construction, their environmental integration remains weak and inconsistent. A range of strategic interventions are therefore proposed to promote sustainability-oriented supply chain reform. These strategies address gaps in digital infrastructure, policy harmonization, capacity development, vendor engagement, and organizational restructuring.

The first priority must be to accelerate the adoption of digital sustainability tools. Although technologies such as Building Information Modelling (BIM), Internet of Things (IoT), and ERP platforms are increasingly recognized, their deployment is rarely directed at environmental performance indicators. Construction firms, particularly SMEs, require targeted financial and technical support to implement these tools effectively. Government bodies and industry associations should develop standardized digital modules that track carbon emissions, material reuse, and waste generation during project execution. This could be supported through subsidies, cloud-based platforms, and simplified compliance templates that encourage digital onboarding for smaller contractors.

Green procurement also needs institutionalization. Findings suggest that most projects lack structured processes for selecting environmentally qualified vendors. This can be addressed by establishing a national green vendor registry, supported by third-party certification of suppliers based on sustainability metrics. Such a registry would streamline procurement while ensuring consistent quality and environmental compliance. Procurement officers should also be trained in life-cycle costing and eco-efficiency principles, enabling informed decision-making that balances economic and environmental objectives.

The lack of structured environmental risk governance calls for the formal integration of tools such as FMEA, the House of Risk model, and scenario-based planning into construction project workflows. These frameworks, widely used in manufacturing, can be adapted to assess environmental and logistical risks in construction supply chains. Industry bodies like the Construction Industry Development Council (CIDC) and the Indian Green Building Council (IGBC) should co-develop SSCM certification programs tailored to procurement and project management staff.

Policy harmonization is equally essential. Interviews revealed frequent regulatory delays and contradictory environmental standards across state jurisdictions. To address this, state-level SSCM facilitation centers should be created to provide technical support and expedite compliance clearances. Additionally, a centralized digital portal can be launched for green documentation, vendor registration, and material tracking. Such institutional reforms would help reduce lead times, improve transparency, and standardize sustainability reporting.

Organizational readiness must also be improved. Many firms still perceive supply chain operations as operational tasks, with little strategic or environmental relevance. It is imperative to embed sustainability roles such as Environmental Procurement Officers or SSCM Managers within firms, equipped with clearly defined KPIs linked to emissions reduction, waste minimization, and green sourcing. Cross-functional collaboration should be institutionalized across project planning, procurement, and environmental monitoring departments.

Finally, the development of a national Construction Supply Chain Sustainability Index (CSSI) is proposed. This index, administered by the Ministry of Housing and Urban Affairs and NITI Aayog, would benchmark project performance across dimensions such as digital maturity, green procurement, emissions control, and risk compliance. Firms scoring high on this index could be granted preferential access to public tenders, funding incentives, or environmental certifications. The CSSI would also provide critical data for future research and policymaking, offering a standardized lens through which India's construction sector can track its sustainability trajectory.

Together, these interventions present a cohesive strategy to drive SSCM transformation in Indian construction. They also align with India's broader environmental commitments under the Paris Agreement, Nationally Determined Contributions (NDCs), and the United Nations Sustainable Development Goals (SDGs), particularly Goal 9 (Industry, Innovation, and Infrastructure) and Goal 12 (Responsible Consumption and Production).

6. CONCLUSION

This study offers a comprehensive empirical evaluation of sustainable supply chain management (SSCM) practices across various construction project types in India. Through a mixed-methods approach combining quantitative data from 487 respondents and qualitative insights from 20 expert interviews, the research identifies critical gaps, sectoral disparities, and enablers of environmental performance in the Indian construction supply chain ecosystem.

Infrastructure and industrial projects, often supported by centralized procurement and formal digital systems, were found to demonstrate relatively advanced SSCM maturity. In contrast, residential and SME-led commercial projects remain fragmented and underdeveloped in their environmental orientation. Key weaknesses include the limited adoption of digital tools for sustainability monitoring, lack of structured environmental risk management, poor vendor integration, and inadequate organizational investment in SSCM governance. Despite growing interest in technologies like BIM and ERP, most firms continue to use them for operational efficiency rather than ecological tracking or emissions reduction.

Regulatory inconsistency and bureaucratic inertia remain significant bottlenecks, particularly for projects outside major urban centers. Furthermore, the perception of supply chain functions as back-office support roles, rather than strategic levers of environmental performance, inhibits meaningful transformation. The absence of sustainability-focused training, certification, and leadership roles compounds this issue, especially in smaller organizations that lack the capacity to navigate complex green procurement protocols.

To address these systemic challenges, the study proposes a multi-dimensional strategy encompassing digital modernization, formal risk integration, procurement reform, regulatory harmonization, and organizational restructuring. Importantly, these solutions must be contextualized to India's construction landscape, taking into account variations in project scale, region, and institutional capacity.

Ultimately, SSCM transformation in the Indian construction sector is not merely a technical endeavour it requires a fundamental cultural and institutional shift. By investing in structured sustainability governance, robust digital platforms, and inclusive policy frameworks, India can position its construction sector as a global leader in environmentally responsible infrastructure development. The successful implementation of SSCM reforms will not only enhance efficiency and resilience but also contribute meaningfully to climate mitigation, resource conservation, and long-term ecological balance.

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