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Green Supply Chain Management in the Cement Manufacturing Sector in India: Challenges, Practices, and Future Directions

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***Abstract*-- The cement manufacturing industry in India is one of the most carbon-intensive sectors, accounting for approximately 7–8% of the country's total CO_2 emissions. Green Supply Chain Management (GSCM) has emerged as a strategic imperative to reconcile industrial growth with environmental sustainability. This paper presents a comprehensive analysis of GSCM practices within India's cement sector, examining the conceptual framework, regulatory landscape, current adoption levels, key challenges, and potential future directions. Using a systematic review of peer-reviewed literature, industry reports, and governmental policy documents, this study identifies critical GSCM dimensions including green procurement, eco-design, reverse logistics, green manufacturing, and environmental collaboration. The findings reveal that while large conglomerates such as UltraTech Cement, ACC, and Shree Cement have made notable strides in integrating sustainability into supply chain operations, small and medium-sized producers continue to lag due to financial constraints, lack of technical expertise, and inadequate regulatory enforcement. The paper also highlights opportunities presented by circular economy principles, digitalization, and India's climate commitments under the Paris Agreement to accelerate GSCM adoption. This research contributes to the growing literature on industrial sustainability in emerging economies and offers actionable recommendations for policymakers, industry practitioners, and researchers.**

***Keywords*-- Green Supply Chain Management, Cement Industry, Sustainability, India, Circular Economy, Carbon Emissions, Environmental Management**

I. INTRODUCTION

The global cement industry occupies a paradoxical position in the discourse on sustainable development. As one of the foundational inputs for infrastructure—from roads and bridges to housing and industrial facilities—cement is indispensable to economic growth. Yet its production is among the most resource- and energy-intensive of all industrial processes, generating approximately 0.8 tonnes of CO_2 per tonne of cement produced (Benhelal et al., 2013).

India, as the world's second-largest cement producer after China, produced over 370 million tonnes of cement in 2022–23, making the country's cement sector a critical actor in both its developmental trajectory and its environmental obligations (Cement Manufacturers' Association, 2023).

Globally, the recognition that conventional supply chain models are unsustainable has driven the emergence of Green Supply Chain Management (GSCM) as a strategic discipline. GSCM integrates environmental thinking into supply chain management, encompassing product design, material sourcing, manufacturing processes, final product delivery, and end-of-life management (Srivastava, 2007). In the Indian context, GSCM in cement manufacturing is particularly salient given the sector's heavy dependence on natural resources such as limestone, the high energy demands of clinker production, and the significant air and water pollution associated with plant operations.

India's commitment under the Paris Agreement to reduce the emissions intensity of its GDP by 45% from 2005 levels by 2030, and its domestic policies such as the National Action Plan on Climate Change (NAPCC), have placed mounting pressure on energy-intensive industries to adopt greener operational paradigms (Ministry of Environment, Forest and Climate Change [MoEFCC], 2021). Additionally, the Bureau of Energy Efficiency's Perform, Achieve and Trade (PAT) scheme directly targets energy consumption in cement plants, creating compliance-driven incentives for greening supply chains.

Despite growing awareness, empirical research specifically examining GSCM adoption in India's cement industry remains sparse. Most existing literature either focuses on broader manufacturing sectors (Diabat & Govindan, 2011; Zhu et al., 2008) or addresses isolated sustainability practices without offering a holistic, sector-specific analysis. This paper seeks to fill that gap by synthesising existing scholarly work, grey literature, and policy documents to offer a comprehensive picture of GSCM in Indian cement manufacturing.

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The remainder of this paper is structured as follows: Section 2 reviews the theoretical foundations and conceptual framework of GSCM. Section 3 provides an overview of the Indian cement industry. Section 4 examines GSCM drivers and regulatory context. Section 5 analyses current GSCM practices. Section 6 discusses major challenges. Section 7 explores future directions, and Section 8 concludes with implications and recommendations.

II. Theoretical Framework And Literature Review

2.1 Defining Green Supply Chain Management

Green Supply Chain Management is broadly defined as the integration of environmental considerations into supply chain management practices, from the procurement of raw materials through to the disposal of end products (Srivastava, 2007). The concept draws on multiple theoretical traditions, including the Natural Resource-Based View (NRBV) of the firm (Hart, 1995), Institutional Theory (DiMaggio & Powell, 1983), and Stakeholder Theory (Freeman, 1984). The NRBV posits that firms can achieve sustainable competitive advantage by developing capabilities linked to the natural environment, encompassing pollution prevention, product stewardship, and clean technology development.

Green (1996) and subsequently Handfield et al. (1997) were among the first to systematically articulate the relationship between environmental management and supply chain operations. Their work established that environmental performance could not be achieved in isolation by a single firm but required coordinated action across the supply chain network. This insight has shaped subsequent research, which has explored GSCM across dimensions including green procurement, green design, green manufacturing, green distribution/marketing, and reverse logistics (Zhu et al., 2008).

2.2 Key GSCM Dimensions

Green Procurement refers to the selection of suppliers and materials based on environmental criteria in addition to traditional cost and quality metrics (Handfield et al., 1997). In cement manufacturing, this encompasses the sourcing of alternative raw materials such as fly ash and slag to partially substitute clinker, as well as the procurement of energy from renewable sources. Green Design involves designing products and processes to minimise environmental impact throughout the product lifecycle (Rao, 2002). For cement, this includes developing blended cements with lower clinker-to-cement ratios, which reduce CO_2 emissions per unit of output.

Green Manufacturing focuses on minimising waste and emissions during production through energy efficiency measures, waste heat recovery, and the adoption of alternative fuels and raw materials (AFR). Reverse Logistics encompasses the processes of collecting, sorting, and reprocessing waste materials back into the production cycle—a practice strongly aligned with circular economy principles (Rogers & Tibben-Lembke, 1999). Environmental Collaboration involves working with suppliers, customers, and other stakeholders to jointly achieve environmental goals (Vachon & Klassen, 2008). Finally, Environmental Monitoring and Reporting refers to systems for tracking, measuring, and disclosing environmental performance data.

2.3 Empirical Evidence from Emerging Economies

A substantial body of empirical research has examined GSCM adoption and performance in emerging economies. Zhu et al. (2008) surveyed 341 Chinese manufacturing firms and found that proactive GSCM practices were positively associated with both environmental and economic performance, though the relationship was moderated by institutional pressures. Diabat and Govindan (2011) identified 11 key GSCM drivers for Indian industries through an interpretive structural modelling approach, finding regulatory compliance and top management commitment to be the most influential. Govindan et al. (2014) conducted a meta-analysis of 191 articles and established that supplier environmental collaboration and eco-design were the most widely studied and impactful GSCM practices.

Studies specifically focused on the Indian context have highlighted the role of regulatory pressure, customer pressure, and competitive advantage as key antecedents to GSCM adoption (Mudgal et al., 2010; Rao, 2002). However, the cement sector has received limited dedicated scholarly attention compared to sectors such as automotive, textiles, and electronics. This gap represents a significant lacuna, given cement's outsized environmental footprint and strategic economic importance.

III. Overview Of The Indian Cement Industry

3.1 Structure and Scale

India's cement industry is the second-largest in the world, with an installed capacity exceeding 600 million tonnes per annum (MTPA) as of 2023 (Cement Manufacturers' Association, 2023). The sector comprises approximately 210 large cement plants and over 350 mini cement plants spread across 29 states.

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The industry is characterised by a dualistic structure: a handful of large integrated conglomerates—including UltraTech Cement, Shree Cement, ACC, Ambuja Cements, and Dalmia Bharat—account for a majority of production, while a long tail of smaller regional players serve local markets.

Geographically, production is concentrated in states rich in limestone deposits, particularly Rajasthan, Madhya Pradesh, Andhra Pradesh, Telangana, Gujarat, and Chhattisgarh. The Rajasthan-Gujarat corridor is home to some of the world's largest and most energy-efficient cement clusters. Demand is driven primarily by the housing and infrastructure construction sectors, and has been given a structural boost by the Government of India's flagship programmes such as Pradhan Mantri Awaas Yojana (PMAY) and the National Infrastructure Pipeline (NIP).

3.2 Environmental Profile

The cement production process is inherently carbon-intensive. The principal source of CO_2 emissions is the calcination of limestone ($CaCO_3 \rightarrow CaO + CO_2$), which accounts for approximately 60% of total process emissions, with the remainder attributable to fuel combustion for kiln operations (Benhelal et al., 2013). Indian cement plants consume an average of 725–750 kcal of thermal energy per kilogramme of clinker—higher than global best practices of around 680 kcal/kg—reflecting the prevalence of older wet-process and semi-dry kilns in segments of the industry (Bureau of Energy Efficiency [BEE], 2022).

Beyond carbon, the industry is a significant source of particulate matter (PM), nitrogen oxides (NO_x), and sulphur dioxide (SO_2), and is a major consumer of water, limestone, coal, and land. Quarrying activities generate habitat fragmentation and groundwater depletion, while waste disposal from fly ash ponds poses risks of soil and water contamination. The social and environmental impacts of cement manufacturing are thus multi-dimensional, extending well beyond the plant gate into surrounding ecosystems and communities.

3.3 Industry Sustainability Initiatives

In response to regulatory pressures and voluntary commitments, major Indian cement companies have launched a range of sustainability programmes. UltraTech Cement, India's largest cement producer, has committed to achieving net-zero carbon emissions by 2050 and has significantly increased its use of waste-derived fuels through its Alternative Fuels and Raw Materials (AFR) programme (UltraTech Cement, 2023).

ACC Limited, a subsidiary of Holcim, has implemented the Geocycle waste co-processing platform, diverting industrial and municipal waste from landfills and substituting fossil fuels (ACC Limited, 2022). Shree Cement has consistently ranked among the most energy-efficient cement producers globally, with a specific electrical energy consumption significantly below the industry average.

IV. Drivers And Regulatory Context For GSCM In Indian Cement

4.1 Regulatory Drivers

The regulatory framework governing environmental performance in India's cement sector is multilayered, involving central government ministries, state pollution control boards, and sector-specific agencies. The Environment (Protection) Act, 1986, and the Air (Prevention and Control of Pollution) Act, 1981, provide the foundational legal basis for emission standards and environmental compliance. The Ministry of Environment, Forest and Climate Change (MoEFCC) has issued Environment Impact Assessment (EIA) notification requirements for new and expanded cement plants, mandating comprehensive assessments of environmental and social impacts prior to project approval.

The Central Pollution Control Board (CPCB) has progressively tightened emission norms for cement plants, establishing limits for particulate matter, SO_2, NO_x, and mercury. The 2016 revision of emission standards introduced significantly stricter limits, requiring major capital investment in pollution control equipment such as electrostatic precipitators and bag filters across the industry (CPCB, 2016). The Bureau of Energy Efficiency's PAT scheme, launched under the Energy Conservation Act, 2001, has been particularly influential. Under PAT Cycles I through IV, cement plants have collectively achieved energy savings equivalent to millions of tonnes of oil equivalent, and PAT has created a market-based mechanism for trading energy saving certificates (ESCerts) that incentivises over-performance (BEE, 2022).

India's Nationally Determined Contribution (NDC) under the Paris Agreement commits the country to reducing the emissions intensity of GDP by 45% from 2005 levels by 2030 and achieving approximately 50% of cumulative installed electric power capacity from non-fossil fuel sources by 2030 (MoEFCC, 2021). These national-level commitments translate into sectoral obligations that are increasingly shaping corporate environmental strategy in cement manufacturing.

4.2 Market and Competitive Drivers

Beyond regulatory compliance, competitive dynamics and market pressures are increasingly motivating GSCM adoption. International buyers, particularly government procurement agencies and multinational infrastructure developers, are incorporating green building standards such as LEED and GRIHA into their project requirements, creating demand-pull for low-carbon cement products (Indian Green Building Council [IGBC], 2022). The growing market for blended cements—which carry lower carbon footprints than ordinary Portland cement—reflects both regulatory support and changing customer preferences.

Access to international capital markets has also emerged as a driver. Several Indian cement companies have issued green bonds to finance sustainability investments, and adherence to Environmental, Social, and Governance (ESG) criteria has become increasingly important for attracting institutional investment (Securities and Exchange Board of India [SEBI], 2021). The adoption of ESG reporting frameworks such as the Global Reporting Initiative (GRI) and the Task Force on Climate-related Financial Disclosures (TCFD) has further institutionalised sustainability performance tracking.

4.3 Internal Organisational Drivers

Internal drivers include top management commitment, organisational culture, cost reduction motivations, and the desire to build reputational capital. Research on Indian manufacturing firms consistently identifies top management support as the most critical internal enabler of GSCM adoption (Diabat & Govindan, 2011; Mudgal et al., 2010). Cost considerations also play a dual role: while upfront investment in green technologies can be substantial, energy efficiency improvements and waste reduction generate operational savings that provide a business case for GSCM. The cement industry's high energy costs—energy constitutes 25–30% of total production costs in India—make energy efficiency a particularly compelling economic argument for green operations (Cement Manufacturers' Association, 2023).

V. Current GSCM Practices In Indian Cement Manufacturing

5.1 Green Procurement

Green procurement in the Indian cement sector manifests primarily through the increased utilisation of industrial by-products as supplementary cementitious materials (SCMs).

Fly ash, a by-product of coal combustion in thermal power plants, and ground granulated blast furnace slag (GGBFS), a by-product of steel manufacturing, are widely used as partial substitutes for clinker in blended cements. The Bureau of Indian Standards (BIS) has standardised several blended cement types, including Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC), facilitating their widespread adoption. India's fly ash utilisation rate in cement manufacturing has improved significantly, with over 180 million tonnes consumed annually across the sector (Fly Ash Unit, Ministry of Environment, 2022).

Procurement of alternative fuels is another dimension of green purchasing. Cement kilns, operating at temperatures exceeding 1,400°C with long residence times, are technically well-suited for co-processing a wide range of waste materials as alternative fuels, including municipal solid waste, agricultural residues, industrial sludge, and end-of-life tyres. The Thermal Substitution Rate (TSR)—the share of thermal energy derived from alternative fuels—averaged approximately 6% for the Indian cement industry in 2022, well below the global average of over 20% for developed country producers (Global Cement and Concrete Association [GCCA], 2022). However, leading producers have achieved significantly higher TSRs, with some plants approaching 30%, indicating the technical feasibility of scaling up AFR utilisation.

5.2 Eco-Design and Product Innovation

The most significant product-level green innovation in cement manufacturing is the development of low-clinker blended cements and novel low-carbon binders. Reducing the clinker-to-cement ratio (c/r) is the most cost-effective lever for reducing CO_2 emissions, as clinker production is the single largest source of process emissions. The average clinker-to-cement ratio in India was approximately 0.72 in 2022, compared to a global best practice target of below 0.65 (GCCA, 2022). Initiatives to reduce this ratio, through increased use of SCMs and optimisation of blending formulations, represent a core dimension of eco-design strategy.

Several Indian companies are investing in research and development for next-generation low-carbon cements, including alkali-activated materials (geopolymers), belite-calcium sulphoaluminate (BCSA) cements, and carbonation-cured concrete. While these technologies remain at varying stages of commercial readiness, they represent the frontier of eco-innovation in the sector. Dalmia Bharat and ACC have reported pilot projects and research collaborations in this domain (Dalmia Bharat, 2023; ACC Limited, 2022).

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5.3 Green Manufacturing and Energy Efficiency

Energy efficiency improvements are the dominant expression of green manufacturing in Indian cement. Key measures include the conversion of wet and semi-dry process kilns to the more efficient dry-process technology, deployment of waste heat recovery systems (WHRS) to generate electricity from kiln exhaust gases, and installation of variable frequency drives and high-efficiency motors. The PAT scheme has been instrumental in driving these investments. By the end of PAT Cycle IV (2022), the cement sector had achieved cumulative energy savings of over 10 million tonnes of oil equivalent (Mtoe), translating into significant reductions in both energy costs and carbon emissions (BEE, 2022).

Waste heat recovery has emerged as a particularly impactful technology. WHRS systems can generate 20–30 kWh of electricity per tonne of clinker, reducing dependence on grid power and lowering the carbon footprint of electricity consumption. As of 2023, India had approximately 50 WHRS installations in cement plants, with a combined capacity exceeding 1,000 MW—though significant additional potential remains untapped, particularly among mid-sized producers (Indian Cement Review, 2023).

Water stewardship has gained increasing attention as a GSCM dimension in water-stressed regions. Major producers have implemented closed-loop water recycling systems, rainwater harvesting, and watershed development programmes around plant sites. UltraTech Cement reports achieving positive water balance in several of its plants through these measures (UltraTech Cement, 2023).

5.4 Reverse Logistics and Circular Economy

The circular economy represents perhaps the most transformative framework for rethinking GSCM in cement manufacturing. At its core, the cement industry can function as a metaboliser of industrial and municipal waste, converting materials that would otherwise be disposed of into fuel and raw material inputs. Co-processing of waste in cement kilns—encompassing both AFR utilisation and material recovery—is the primary mechanism through which circular economy principles are operationalised in the sector.

Beyond co-processing, some companies have developed programmes to recover and recycle concrete demolition waste. Crushed concrete rubble can substitute for natural aggregates in concrete production, reducing quarrying demand. While the market for recycled aggregates remains nascent in India due to the absence of specific standards and limited contractor awareness, pilot projects by Holcim India and others indicate growing momentum (Holcim India Sustainability Report, 2022). The integration of extended producer responsibility (EPR) principles, drawing on models from the packaging and electronics industries, represents a longer-term opportunity for formalising reverse logistics in the cement value chain.

5.5 Environmental Collaboration and Reporting

Supply chain collaboration on environmental issues has increased among leading Indian cement producers. This includes engagement with key suppliers on energy and emissions performance, joint development of environmental standards for logistics and transport partners, and participation in industry-wide initiatives such as the GCCA's 2050 Roadmap and the Low Carbon Technology Partnerships initiative (LCTPi). Many companies have also established supplier sustainability assessment programmes, incorporating environmental criteria into supplier qualification and performance evaluation processes.

Environmental reporting has become increasingly institutionalised, driven by SEBI's Business Responsibility and Sustainability Reporting (BRSR) framework, which mandates sustainability disclosures for the top 1,000 listed companies in India by market capitalisation (SEBI, 2021). All major listed cement producers now publish annual sustainability or integrated reports aligned with GRI Standards, providing data on energy consumption, carbon emissions, water withdrawal, waste generation, and biodiversity impacts. This transparency has both accountability and benchmarking benefits, enabling stakeholders to compare performance across the industry.

5.6 Summary of GSCM Practice Adoption

Table 1 summarises the relative adoption levels of key GSCM practices across different segments of the Indian cement industry.

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Table 1.
GSCM Practice Adoption Levels in Indian Cement Industry (Authors' Assessment Based on Literature Review)

GSCM Practice	Large Producers	Mid-Sized Producers	Small Producers
Green Procurement (SCMs/AFR)	High	Moderate	Low
Eco-Design / Low-Clinker Cements	High	Moderate	Low
Waste Heat Recovery	High	Low–Moderate	Negligible
Alternative Fuels Co-Processing	Moderate–High	Low–Moderate	Low
Reverse Logistics / Circular Economy	Moderate	Low	Very Low
Environmental Collaboration	Moderate–High	Low	Very Low
ESG Reporting	High	Low–Moderate	Low

VI. Key Challenges To GSCM Adoption

6.1 Financial and Investment Barriers

The high capital intensity of green technology investments constitutes a principal barrier to GSCM adoption, particularly for smaller producers. Technologies such as waste heat recovery systems, advanced pollution control equipment, and renewable energy infrastructure require substantial upfront investment with payback periods that may extend beyond the planning horizons of smaller firms. Access to affordable green finance remains uneven, with smaller and non-listed companies facing higher costs of capital and limited access to green bond markets or sustainability-linked loans (International Finance Corporation [IFC], 2022).

6.2 Technical and Knowledge Barriers

Technical barriers include the lack of in-house expertise in environmental management systems, limited familiarity with international best practices, and the absence of industry-wide platforms for technology diffusion. The waste management infrastructure required to support co-processing—including waste collection, characterisation, preprocessing, and quality assurance systems—remains underdeveloped in many parts of India, constraining the ability of cement plants to scale up AFR utilisation (Cement Manufacturers' Association, 2023).

Additionally, the variability in quality and calorific value of available waste streams poses operational challenges for kiln management.

6.3 Regulatory and Institutional Barriers

Despite a comprehensive policy framework on paper, enforcement remains inconsistent, particularly at the state level. The capacity of State Pollution Control Boards (SPCBs) to monitor and enforce compliance varies considerably across states, creating regulatory arbitrage opportunities that disadvantage compliant producers (Pargal & Wheeler, 1996; Sinha, 2016). The fragmented and sometimes contradictory nature of waste classification and permitting rules—which govern the ability of cement plants to receive and co-process certain waste categories—creates administrative uncertainty and increases transaction costs for AFR programmes.

6.4 Supply Chain Complexity and Coordination Failures

The cement supply chain involves a diverse array of actors—raw material suppliers, fuel providers, waste generators, logistics companies, distributors, and end consumers—whose interests and environmental capabilities vary widely. Coordinating GSCM initiatives across this complex network is inherently challenging. Information asymmetries between large producers and their smaller suppliers and distributors impede the implementation of supply chain-wide environmental standards.

The informal and fragmented nature of construction material supply chains in India further complicates traceability and accountability (Vachon & Klassen, 2008).

6.5 Consumer Awareness and Demand Constraints

At the demand end of the supply chain, consumer awareness of green cement products remains limited. The Indian construction sector—dominated by individual house builders, small contractors, and government project developers—has historically prioritised cost and availability over environmental attributes in procurement decisions. The green building market, while growing rapidly, still accounts for a small fraction of total construction activity. Until green credentials command a meaningful price premium or become a standard procurement requirement, demand-side incentives for GSCM will remain constrained (IGBC, 2022).

VII. Future Directions And Opportunities

7.1 Circular Economy Integration

The circular economy provides a compelling strategic framework for radically transforming GSCM in cement manufacturing. Moving beyond incremental improvements in energy efficiency and waste reduction, a circular cement economy would involve the design of closed-loop material flows in which waste outputs from one industry become inputs to the cement value chain, and demolished concrete structures are systematically recovered and recycled. India's accelerating urbanisation and the resulting flows of construction and demolition (C&D) waste present a significant opportunity: annual C&D waste generation is estimated at 150–350 million tonnes, with only a fraction currently recovered (Ministry of Housing and Urban Affairs [MoHUA], 2020). Policy frameworks for C&D waste management, together with investment in material recovery facilities, could unlock substantial volumes of secondary raw materials and reduce the industry's dependence on virgin limestone.

7.2 Digitalisation and Industry 4.0

The digitalisation of supply chain operations offers transformative potential for GSCM in cement. Advanced metering and sensor technologies, connected to Industrial Internet of Things (IIoT) platforms, enable real-time monitoring of energy consumption, emissions, and operational parameters, facilitating continuous improvement and predictive maintenance. Artificial intelligence and machine learning applications can optimise kiln operations, reducing specific energy consumption and emissions variability.

Blockchain-based supply chain traceability solutions offer the prospect of verifiable environmental claims throughout the supply chain, addressing credibility concerns around green procurement and sustainability reporting (Saberi et al., 2019).

Digital platforms can also facilitate waste-to-resource matching, connecting cement producers with waste generators to streamline the procurement of alternative fuels and raw materials. Several technology startups in India are developing waste exchange platforms that could significantly reduce transaction costs in the AFR market (NITI Aayog, 2020).

7.3 Carbon Capture, Utilisation, and Storage (CCUS)

For the cement industry to achieve deep decarbonisation—approaching net-zero emissions—Carbon Capture, Utilisation, and Storage (CCUS) technologies will likely be indispensable. Process CO_2 from clinker calcination cannot be eliminated through energy efficiency or fuel switching alone, making carbon capture a necessary component of long-term decarbonisation pathways (IEA, 2020). While CCUS technology in cement remains at an early commercial stage globally, and its application in India faces additional challenges related to geological storage capacity and capital costs, the trajectory of technology development and the declining costs of CO_2 capture suggest that CCUS could become economically viable in the 2030–2040 timeframe.

7.4 Policy and Institutional Reforms

The realisation of GSCM's potential in the cement sector requires supportive policy reforms at multiple levels. Strengthening the environmental regulatory enforcement capacity of SPCBs, harmonising waste classification rules to facilitate co-processing, and expanding the PAT scheme to cover a broader range of environmental performance metrics are among the priority institutional reforms. The introduction of a carbon pricing mechanism—whether a carbon tax or an extension of the existing energy intensity trading scheme toward an explicit carbon price—would create stronger price signals for decarbonisation investment (Parikh et al., 2009). Green public procurement requirements for cement in government construction projects could create significant demand-pull for environmentally superior products, leveraging the government's dominant role as a construction client.

7.5 Capacity Building and Knowledge Diffusion

Addressing the knowledge and capability gaps that constrain GSCM adoption among smaller producers requires targeted interventions.

Industry associations such as the Cement Manufacturers' Association (CMA) can play a pivotal role in developing best practice guidelines, organising knowledge-sharing forums, and facilitating technology demonstrations. Academic and research institutions can contribute through applied research, case study development, and training programmes. Development finance institutions, including the International Finance Corporation and the Asian Development Bank, have established technical assistance programmes for green industry in India that could be tailored to the specific needs of the cement sector.

VIII. CONCLUSION

This paper has provided a comprehensive review of Green Supply Chain Management in India's cement manufacturing sector, tracing the conceptual foundations, regulatory context, current practices, challenges, and future directions of sustainability integration in one of the country's most environmentally significant industries. The analysis reveals a heterogeneous landscape in which a cohort of large, internationally connected producers has made meaningful progress in greening their supply chains, while the broader industry continues to face structural barriers to more widespread adoption.

The cement sector's strategic importance for India's development ambitions, combined with its outsized environmental footprint, makes it a critical arena for the operationalisation of sustainable industrial policy. GSCM offers a systemic framework for simultaneously addressing competitiveness, compliance, and climate objectives. The pathways identified in this paper—circular economy integration, digitalisation, CCUS, policy reform, and capacity building—are not mutually exclusive but are mutually reinforcing components of a comprehensive sustainability transformation.

The research contributes to the literature on industrial sustainability in emerging economies by providing a sector-specific, evidence-based analysis of GSCM in a context characterised by rapid industrial growth, complex regulatory governance, and acute environmental pressures. Future research should prioritise longitudinal empirical studies of GSCM performance outcomes in Indian cement companies, comparative analyses of GSCM strategies across different firm sizes and ownership types, and the development of sector-specific GSCM measurement frameworks. As India charts its course toward a net-zero economy while sustaining rapid economic growth, the transformation of the cement supply chain will be both a significant challenge and a significant opportunity.

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