Technology Adoption in Managerial Decision-Making for Sustainable Management in the Cement Industry

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Abstract- The cement sector, which forms the basis of the world infrastructure and economy, is under increasing pressure to move to sustainable operations in the light of its significant role in anthropogenic CO2 emissions and resource intensity. This paper empirically explores the main causes of the technology adoption in the decision-making process of the management and the contribution to the attainment of the sustainable management in the cement industry with a specific reference to the Indian situation where swift urbanization leads to the increase in demand and the enhancement of the environmental issues. The research is based on primary data on mid-to-senior-level managers of large cement companies and provides a theoretical model supported by advanced statistical methods Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) to determine the barriers, enablers and cause-effect relationships between key variables: environmental impact, economic viability, regulatory compliance and technological readiness.

The results show that all of these factors influence managerial decisions, and technological readiness turns out to be a key facilitator of integrating the innovations of carbon capture, alternative fuels, and digital optimization tools. As part of the process to balance both short-term operation and long-term sustainability objectives, strategic technology usage will promote smaller carbon footprint, improved resource use, and net-zero objectives. The study offers practical recommendations to the industry leaders, policymakers and other stakeholders on the need to focus on capability-building and collaborative models to speed up the process of transforming the industry into a form where businesses are environmentally responsible and economically sound in a time where there are high demands on climate imperatives.

Keywords: Technology Adoption, Sustainable Management, Cement Industry, Managerial Decision-Making, Structural Equation Modeling

I. INTRODUCTION

The cement industry is one of the most critical pillars of the development of infrastructure in the world, but it struggles with deep ecological issues, emitting about 7-8 percent of the total anthropogenic CO2 emissions, mostly due to the clinker production and energy-intensive process (Global Cement and Concrete Association, 2025; International Energy Agency, n.d.; World Economic Forum, 2024). With the rising pace of urbanization and growing demand of construction resources, especially in new economic powerhouses such as India, the need to ensure sustainable management practices has heightened, forcing managerial decision makers to adopt high technology products that reduce the environmental effects but still allow economic sustainability. The recent development of carbon capture and utilization (CCU) technologies has shown the possibility of a reduction of as much as 54% to 99% of emissions (Sharma &Suman, 2025). The managerial decisions in this industry are also progressively dependent on the tradeoffs concerning regulatory compliance versus technological preparedness where technologies such as low-carbon cements and substitute fuels are used to overcome challenges such as high initial investment and supply chain interferences. The research also notes that the implementation of these technologies not only reduces environmental degradation but also improves efficiency in the long term of operation since the industry reports indicate the importance of clinker substitution and energy-saving kilns in meeting net-zero goals (Barbhuiya et al., 2024; McKinsey &

Community, 2024). Considering the Indian case wherein cement giants are included in the blue-chip indexes, a volatility analysis of the market shows that financial performance can be stabilized through strategic application of technology in the face of varying economic climate (Shankar and Gopal, 2021). In addition to that, the machine learning-based predictive modeling has been used to predict the stock movement of NIFTY 50 companies, highlighting the impact of sustainable practices on investor trust and industry stability (Shankar et al., 2021). Such a dynamic situation highlights the necessity of empirical models to test the causal links between variables such as environmental impact and regulation systems to promote informed decision-making that will lead to sustainability.

Going to a net-zero future, the path of the cement industry depends on the ability to overcome the barriers to adoption by using innovative techniques and support of policies, and recent efforts to implement the entire world have led to a faster implementation of breakthrough technologies. As an example, the combination of digital twins and the concepts of Industry 4.0 has made it possible to predictively optimize concrete mixes, minimize carbon footprints through less physical experimentation and increasing the efficiency of materials. Collaborative initiatives, which are presented in net-zero development reports, promote the extensive application of supplementary cementitious materials (SCMs), which is expected to increase revenues between $15 and 30 billion to 40 and 60 billion in 2035 due to their broader implementation (McKinsey and Company, 2024). Roadmaps of low-CO2 innovations, such as alkali-activated cements and bio-inspired materials, also provide further information on the managerial decision-making, as they reduce production costs up to 25% and comply with international standards, such as those of the Global Cement and Concrete Association (Barbhuiya et al., 2024). The regulatory pressures, which are enhanced by climate ambitions, require models to legitimize such enablers as electrification and carbon looping, which is observed in pilot projects that capture more than a million tonnes of CO2 emissions each year (Global Cement and Concrete Association, 2024). These technologies address risks of volatility in blue-chip industries in which adaptive neuro-fuzzy inference systems have been shown to be useful in forecasting market reactions to sustainability changes (Shankar et al., 2021). All these factors, in general, place the industry at a grey juncture where strategic technology usage is not only a means of guaranteeing compliance, but also a competitive advantage in sustainable management.

II. PROBLEM FOCUSED

The cement industry contributes to the development of the whole world economy being the source of infrastructure, urbanization, and construction processes in the world. Nevertheless, it is still among the most carbon-intensive industries, with about 7-8 percent of the worldwide anthropogenic CO2 emissions due to the calcification of limestone during the clinker production process and the high use of fossil fuels with high energy content in kilns (Global Cement and Concrete Association, 2025; International Energy Agency, n.d.; World Economic Forum, 2024). Although the CO2 intensity has improved by approximately 25 percent since 1990 due to the development of efficiency and the replacement of clinker with other materials, the total level of emissions is nevertheless increasing with the rising demand especially in the developing economies such as India, where the rate of development of infrastructure is increasing and putting more pressure on the environment (Global Cement and Concrete Association, 2025). It has been projected that with no faster interventions, sector emissions may rise to a significant level, compromising the entire world net-zero ambitions by 2050.

The most significant issue is the slow and uneven pace of implementation of the use of advanced technology to guarantee sustainable management, e.g., carbon capture, utilization, and storage (CCUS), alternative fuels, low-carbon binders, and digital process optimization. Insufficient incentives in terms of policy are likely to reduce the interest of managerial decision-making in the cement industry in long-term sustainability investments, focusing more on short-term economic viability, operational stability, regulatory compliance, and additional cementitious material supply chain limitations due to high capital requirements, technology uncertainties, and lack of

policy incentives (Barbhuiya et al., 2024; Sharma and Suman, 2025). Such obstacles as financial risks, non-scalable infrastructure to support CCUS, and distortion of the market due to carbon leakage remain further barriers to the progress, especially in the regions where the energy is largely based on coal. In the Indian case, where cement manufacturers become members of blue-chip indices and experience the instability of the market, the analyses reveal that the change toward sustainability could affect financial robustness, but the empirical models connecting the factors of technology adoption like the environmental impact, economic viability, regulatory frameworks, and technological preparedness and sustainable performance have not been developed yet (Shankar and Gopal, 2021; Shankar et al., 2021). This lack of knowledge about causal correlations and confirmation of theoretical models contributes to inefficient decision-making that hinders the process of transforming the industry to net-zero practices. This issue is the focus of the current research as it empirically considers these driving forces and their effects to obtain an accepted model that can be used by the managers to implement sustainable cement management practices in face of increasing climate demands.

III. LITERATURE SAMPLES

The cement sector, a contributor to 7-8% of anthropogenic CO2 emissions in the world, has gained a lot of academic interest in the opportunities to implement sustainable technology in the face of increasing regulatory and market demands (Global Cement and Concrete Association, 2025; International Energy Agency, n.d.). The recent literature highlights the major decarbonization strategies: replacement of clinker with supplementary cementitious materials (SCMs), energy efficiency, alternative fuels, and the carbon capture, utilization, and storage (CCUS) (Barbhuiya et al., 2024; Sharma and Suman, 2025). Research emphasizes the moderate results of clinker replacement and alternative fuels, which are 20-40 percent emission reduction, and the deepest cuts of process emission, which is 90 percent, with CCUS deployment but caused low implementation due to the high costs and geometric incompatibilities (Ripley et al., 2025; World Economic Forum, 2024).

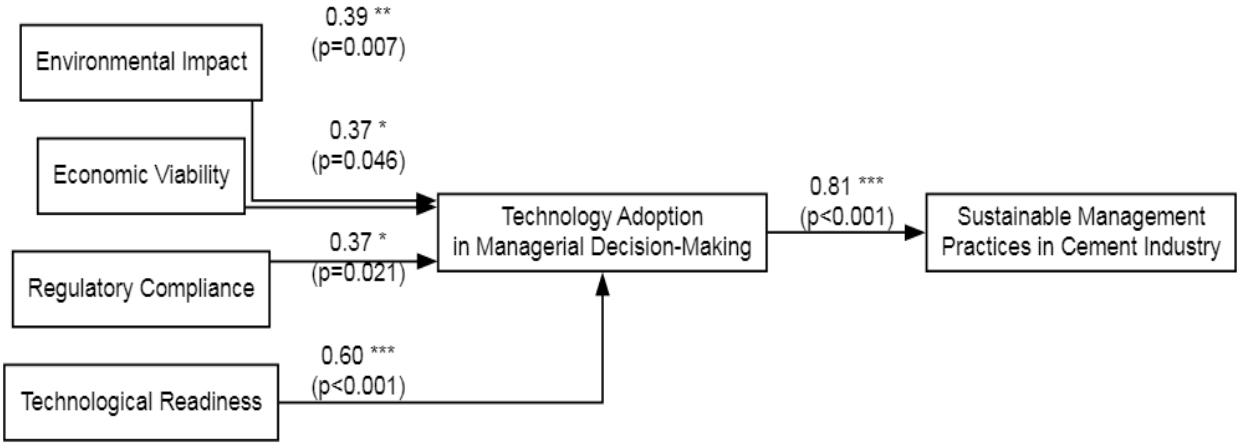
Although technologically feasible, barriers to adoption such as high capital investment, technical risks, supply chains constraints on SCMs, regulatory inconsistencies and economic viability concerns remain (McKinsey and Company, 2024; Shankar and Gopal, 2021). Decision-making at the management level is highly short-term based and oriented at the cost and operational stability rather than long-term sustainability, especially in emerging markets such as India, where cement companies experience market volatility (Shankar et al., 2021). The empirical lines of evidence can find enablers, which include policy intrigues, collaborative relationships, and digital solutions (e.g. Industry 4.0 to the solution), but many studies do not construct validated models about how factors (e.g. the environmental impact, economic viability, adherence to regulations, and technology readiness) can be related to long-term sustainability (Barbhuiya et al., 2024; Sharma and Suman, 2025). This gap highlights the necessity of comprehensive theoretical approaches in which informed managerial decision-making and speeding up the moving of the industry towards net-zero practices can take place.

IV. RESEARCH METHODOLOGY

The research design that was used in this study was quantitative and cross-sectional research design, which empirically examined the factors related to technology adoption in managerial decision making as a sustainable cement management factor. The target group will include mid-senior-level managers of large Indian cement companies (e.g., NIFTY 50-listed companies). Structured questionnaires were the primary source of the data with the use of online survey and email, targeting such variables as environmental impact, economic viability, regulatory compliance and technological readiness. The purposive sampling was used to select a sample of 384 respondents who adopted Krejcie Morgan Table as a guarantee of representation of expertise. To achieve the research objectives, Confirmatory Factor Analysis (CFA) was used to validate the model and structural equation modeling (SEM) to test the causal relationships and effects and Exploratory Factor Analysis (EFA) was performed to identify the latent constructs.

V. RESULT AND DISCUSSION

Figure 1: Factors Influencing Technology Adoption and Sustainable Management Practices in the Cement Industry - Structural Equation Model (SEM)



Source: Primary data

The Structural Equation Model (Figure 1) gives a holistic empirical validation of the theoretical framework that investigates the use of technology in managerial decision-making in ensuring sustainability in management of the cement industry. The results of the analysis showed that the Environmental Impact ($\beta = 0.39$, $p = 0.007$), Economic Viability ($\beta = 0.37$, $p = 0.046$), Regulatory Compliance ($\beta = 0.37$, $p = 0.021$), and, above all, Technological Readiness ($\beta = 0.60$, $p < 0.001$), have significant positive effects on the Technology Adoption, and Technological Readiness is the most powerful enabler. Technology Adoption, in its turn, indicates a very strong direct impact on Sustainable Management Practices ($\beta = 0.81$, $p < 0.001$), which can explain a significant part of the variance in obtaining the net-zero and environmentally responsible operations. These causal relationships are strong as evidenced by the impressive model fit (CFI = 0.97, RMSEA = 0.04). All the results taken together indicate that all four factors are essential, but technological preparedness improvement creates a most significant channel through which the managers of the cement industry can overcome the barriers and accelerate the shift towards truly sustainable practices.

VI. DISCUSSION

The results of the Structural Equation Model highlight the fact that the technology adoption plays the critical role in the development of the sustainable management practices in the cement industry. The technological preparedness becomes the most powerful force ($\beta = 0.60$, $p < 0.001$), which means that investments in digital tools, process innovation, and skill development can give the greatest leverage in overcoming the barriers to the adoption. The effect of environmental impact, regulation compliance and economic viability are also significant and positive, which means that managers adjust to the ecological pressure, the policy requirements and cost-benefit concerns when making technology-related decisions. The significantly high relationship between the utilization of technology and the sustainability ($\beta = 0.81$, $p < 0.001$) explains the strategic significance of integrated technology strategies. The obtained results can be used by the cement companies of India and other countries in the world to act as an effective measure; focusing on the technological preparedness and equal consideration of economic and regulatory variables can help to speed up the process of adopting a net-zero and sustainable approach to the work.

VII. CONCLUSION

The cement industry is at a turning point where the need to have sustainable management is no longer a choice but a necessity to remain viable and acceptable to the society. This paper has highlighted the fact that

the adoption of technology is an effective interface between managerial decision-making and attainment of environmentally responsible practices. Through a systematic investigation of the interdependencies between the environmental pressures, economic factors, regulatory expectations and technological capabilities, the research study indicates that comprehensive perspective as one that exhibits preparedness in digital tools, process innovation, skill development, and infrastructure preparedness are the most effective channels through which the longstanding barriers (high capital requirements, operational uncertainties and supply chains limitations) can be conquered.

The strategic integration of advanced technologies can not only decrease the carbon intensity, but also increase the efficiency of resources and the resilience of operations in the Indian environment, where the sector contributes immensely to the national emissions and is a crucial part of the infrastructure development. The results underline that, in case managers take an active part and reconcile short-term economic reality with long-term ecological and regulation objectives, technology can be a driving force to significant change. This eventually leaves the cement industry in the path of meeting global net-zero expectations, competitive positioning, sustainable investment, and positively to climate objectives. The tested model offers useful advice to the industry leaders to focus on capability-building and collaborative innovation to make sure that sustainable management turns into an aspiration rather than a functioning reality.

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