REFORMING PAKISTAN'S CEMENT INDUSTRY: A CRITICAL PATHWAY TO COMBATING CLIMATE CHANGE

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DOI: https://doi.org/10.5281/zenodo.17440506

Keywords
concrete & cement industry, Climate change, Sustainability, Pakistan.

Article History
Received on 20 Sep 2025
Accepted on 29 Sep 2025
Published on 27 Oct 2025

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Abstract

Cement and concrete, as the most widely produced and used materials globally, pose a significant environmental challenge, chiefly through greenhouse gas emissions and pressure on natural resources like water. As public concern about these impacts' increases, addressing the sustainability issues in their manufacture has grown more urgent. This paper directly examines how the cement and concrete sector affects the environment and explores actionable solutions and innovations suited for implementation in the coming decades to reduce the sector's ecological footprint substantially. Our analysis indicates that promising pathways exist to create a more sustainable concrete industry, improve the balance between societal needs and environmental protection, and leverage advancing technologies.

1. Introduction

Global demand for natural resources is projected to double by 2050, intensifying pressure on finite geological stocks (Rockström et al., 2017). Under current extraction and consumption rates, critical rare-earth elements essential to clean energy—such as lanthanum and yttrium—face depletion. Without institutional changes towards circularity, this ongoing inefficiency—including a global material recycling rate of only 6% (Iacovidou et al., 2021)—threatens to accelerate greenhouse gas emissions and biodiversity decline. Addressing this gap is crucial to achieving long-term sustainability and climate resilience.

Modern construction cannot be carried out without cement and concrete because they offer mechanical strength (the capacity to withstand loads), versatility (ability to be used in many ways), and are universally available (Dwivedi and Singh, 2025). Their hegemony in the built environment, however, is very expensive to the environment. The industry is currently responsible for about 10 percent of the world's total energy-related CO2 emissions, arising from fuel combustion (burning of fuels for heat), electricity use, and calcination (the process of heating limestone to produce clinker) during clinker manufacturing (Antunes et al., 2021). The nature of the chemicals used in cement manufacture means emissions are inevitably hard to remove unless there is process innovation. In addition, low uptake of low-carbon technologies in the industry has made the sector one of the most recalcitrant (resistant to change) to industrial emissions. It is therefore important to transform this sector to mitigate global climate change.

The increase in global population and urbanization is expected to drive continuous increases in infrastructure and housing demand over the next several decades (Karim et al., 2025). This pattern is set to put more strain on cement and concrete production (cement is the primary binding ingredient in concrete), which already has negative environmental effects unless decisive action is taken. The existing momentum of industrial performance, along with economic and technical obstacles, makes the transition to sustainable options challenging. However, a set of new levers, such as alternative binders (materials that can replace or supplement cement in concrete mixes), carbon capture (technologies that remove or store carbon dioxide emissions), and more efficient materials, is promising for decarbonization (Mohamad et al., 2022). To balance development needs and planetary boundaries, these innovations must be complemented by policy and market incentives.

This discussion analyzes how the cement and concrete industry can most effectively reduce its environmental footprint, focusing on actionable, context-specific strategies— especially in rapidly growing economies. Emphasis is given to integrated, technologically viable decarbonization approaches that balance societal needs and ecological boundaries. The discussion builds on recent developments in industrial ecology and climate policy, highlighting scalable interventions that can advance net-zero emission goals (Makul et al., 2021) and directly inform both industry practices and state-level sustainable development policies.

2. Literature Review

2.1 Concrete and Cement Production Environmental Impacts

The production of materials accounts for nearly 25 percent of global greenhouse gas emissions, reflecting the environmental cost of using industrial resources (Poudyal & Adhikari, 2021). Efficiency measures and strategies of the circular economy—an economic system that emphasizes reusing, recycling, and reducing waste—aim to reduce material demand within and across industries, and these hold significant potential to mitigate emissions. The built environment is dominated by concrete and steel, with concrete being the most widely marketed material in the world. Cement is the main binding material in concrete and mortar; as a binder, it holds the aggregate materials together, forming a solid mass (Cerny et al., 2021). Cement production emits a lot of carbon dioxide due to its energy-intensive nature and chemical processes involved, such as the calcination of limestone. With the rapid pace of urbanization worldwide, the sustainability of these base materials is increasingly questionable.

Concrete is a composite material composed of cement, water, sand, and coarse aggregates, and is highly rated for strength, versatility, and low cost (Kanellopoulos, 2021). Its applications are very diverse and include residential and commercial buildings, roads, bridges, dams, and utility systems. Though cement is the smallest component of concrete — approximately 10 percent of its mass —it accounts for approximately 8 percent of worldwide man-made CO2 emissions (Latawiec et al., 2018). Pakistan produces over 4 billion metric tons of cement annually, which is equal to the amount of food produced worldwide (Uddin et al., 2023). This vast scope of production highlights the material as the most crucial aspect in the formation and its ecological effects. It is thus essential to reduce concrete's carbon footprint as a climate action.

Global cement consumption has increased tenfold since the mid-20th century, largely due to population growth, urbanization, and major infrastructure development (Sousa et al., 2023). Cement is used primarily in concrete; about half is also used in mortar, plaster, and precast components. In 2021, global production rose by approximately 4.4 billion tons, a change attributed in part to post-pandemic economic stimulus and renewed construction activity (Drewniok et al., 2023). Despite this expansion, the industry faces rising energy and raw material costs, labor shortages, and logistical constraints. These challenges make meeting demand and reducing emissions difficult. The cement sector remains a significant industrial source of global greenhouse gas emissions.

The ubiquity of concrete has elevated it to a geological marker of the Anthropocene epoch, with an estimated 900 gigatons produced since the Industrial Revolution (Courland, 2022). The cement industry accounts for about 1.5 billion tons of annual carbon dioxide emissions, the same as 300 million cars in Southeast Asian nations (Neupane et al., 2025). In 2024, the industry accounted for 7 percent of total industrial energy use and 22 percent of total process-related industrial greenhouse gas (GHG) emissions worldwide (Uratani & Griffiths, 2023). These statistics demonstrate the imbalance in the climate for one commodity. The further development of concrete use will prevent the world from decarbonizing without systemic changes. The sector needs to be transformed through innovation across the entire life cycle, from production to end-of-life demolition —the process of dismantling or destroying concrete structures once they have reached the end of their useful life.

It requires a joint effort by the four main steps of the value chain of the cement and concrete industry to achieve net-zero emissions (Miller et al., 2021). Raw material excavation and cement production are the initial phases in which the emissions are the greatest. The second involves the production and material specification by the engineers and suppliers. The third involves the design, construction, and long-term use of the buildings by architects, developers, and owners. The last phase entails demolition and recovery, and possible recycling of concrete waste. Decarbonization cannot be achieved in a single stage; all stakeholders should work together to embed sustainability in every decision. Such a systemic approach is necessary to align the construction industry with the climate targets.

The Circular Carbon Economy (CCE) is a comprehensive plan proposed by Pakistan to address carbon emissions across all sectors (Amir & Afzal, 2025). This strategy builds on the conventional reduce, reuse, and recycle rules and introduces a fourth pillar (Reduce, Reuse, Recycle and Remove) that encompasses carbon capture, utilization, and storage (Munir et al., 2024). The CCE model encourages energy conservation, the use of renewable energy, the conversion of CO2 into valuable products, natural carbon sinks, and artificial carbon removal technologies. Although the framework was created with the national energy policy in mind, it provides other countries facing the same struggle with industrial emissions with flexible principles. In Pakistan, where cement demand is increasing rapidly due to urbanization and infrastructure development, the CCE has the potential to serve as an organized channel for balancing growth with climate responsibility. Such strategy implementation would entail policy support, technological investment, and coordination across sectors.

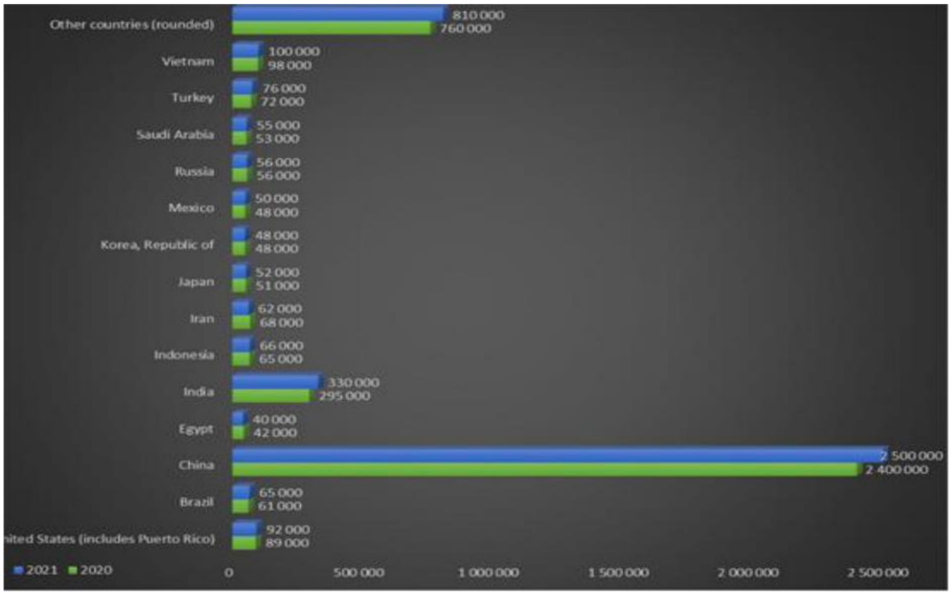

Fig. 1. World cement production (Thousand metric tons)

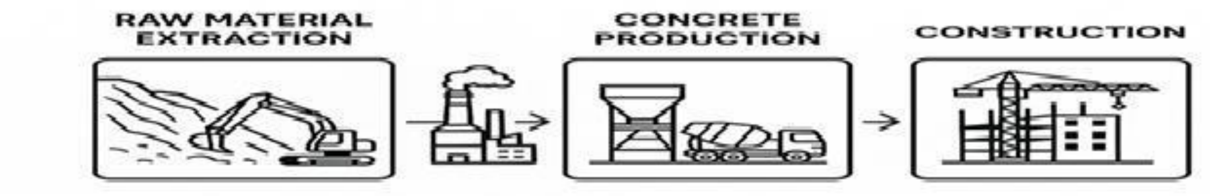

Fig. 2. Key stages of the cement and concrete value chain

3. Challenges and decarbonization strategies in the concrete and cement sector

Concrete and cement production have become major contributors to greenhouse gas (GHG) emissions in Pakistan, driven by decades of rapid infrastructure development (Sheheryar et al., 2021). In 2024 alone, energy allocated to cement manufacturing represented 5.5% of the nation's total final energy consumption. Pakistan possesses one of the highest cement production capacities in the Gulf Cooperation Council region, with an annual capacity of 72.4 million metric tons. As of 2024, Pakistan ranks '10th–15th' globally in cement production, not 8th, with output of 45–50 million tons, about half of the U.S. total (~90 million tons), not 80%. While a key regional producer and exporter, claims of 63 million tons and an 8th-place rank are exaggerated (Uddin et al., 2023). Although production declined to 44.3 million tons by 2019 due to slowed mega-projects and reduced energy subsidies, output remains substantial. Since cement and concrete are widely used in construction, they account for a significant share of the sector's carbon footprint (Javed et al., 2024).

The young and rising population of Pakistan also continues to waste housing, transport, and social infrastructure, which puts pressure on concrete consumption (Sheheryar et al., 2021). Alternative building materials exist, but the workability, durability, and cost-effectiveness of concrete are unique, and therefore, extensive replacement is not possible in the coming decade. This fact requires swift, proactive action to reduce emissions across the construction value chain. But the environmental burden is not limited to carbon emissions; it also encompasses resource losses and local impacts on air quality that cannot be addressed through a marginal increase in efficiency. The development of the regional-specific technological innovation and systemic changes will be necessary to achieve meaningful GHG reductions. The current trend in the sector's emissions will not align with the national commitments to climate change without such interventions.

Pakistan has shown an excellent interest in global climate action by signing international agreements and initiating domestic decarbonization efforts (Mohamad et al., 2022). The key component of this is the Circular Carbon Economy (CCE) model, which has been embraced as a strategic direction for achieving national net-zero by 2060. In the Reduce, Reuse, Recycle, and Remove model introduced in the four pillars of the CCE, the cement and concrete industry plays a significant role in developing the "Reduce" and "Remove" pillars. Mitigating emissions in this industry is necessary not only to decarbonize the industry but also to align the built environment with long-term sustainability objectives. The CCE offers a systematic approach to integrating technological, policy, and circular strategies across the material life cycle.

Within the Reduce pillar, efficiency gains should be achieved at all levels of the construction value chain, including clinker and cement production, concrete mixing, structural design, and building operations (Muller et al., 2021). The major measures involve reducing the clinker-to-cement ratio, using additional cementitious materials like fly ash or slag, and structuring the structures to reduce material use without compromising safety. Such strategies have the potential to significantly reduce concrete's embodied carbon without compromising performance. The extensive implementation would also entail new building codes, professional education, and incentives to encourage low-carbon purchases. Such interventions provide a near-term route to mitigating the sector's environmental impact, but do not interfere with construction activity when done at scale. In addition, the "Remove" component of the CCE focuses on high-tech solutions, such as carbon capture in cement plants and the production of carbon-absorbing concrete products (Javed et al., 2024). New technologies, such as accelerated carbonation curing, enable concrete to serve as a CO2 sink throughout its service life. Also, the recycling of construction and demolition waste should be expanded to establish material loops and reduce dependence on virgin cement. The introduction of recycling activities across the value chain—from production to end-of-life management—facilitates circularity and reduces emissions. Nevertheless, the innovations will be scalable only by overcoming the technical, economic, and regulatory obstacles that currently restrict their implementation in the region (Miller et al., 2021).

The ability of cement to passively reabsorb carbon over time has been an aspect of its environmental profile that many people overlook. Whereas cement production causes high CO2 emissions, the carbon is slowly absorbed by the hydrated phases of concrete in a process known as carbonation (Amir and Afzal, 2025). Recent research projects that this natural sponge effect could eliminate up to 30 percent of total cumulative cement effects over the years 2020-2030. This carbon sink is not fully accounted for in current accounting and policy frameworks, despite its importance. This passive sequestration potential needs to be formally acknowledged in future decarbonization plans and, perhaps, increased through design decisions that increase surface exposure or service life. However, even integrated passive and active sequestration can be insufficient to achieve the 1.5 °C climate goal, and more transformative solutions should be found.

The transformation of the cement and concrete industry in Pakistan will not be successful only with the help of technology but also with conducive policies, availability of resources, and institutional coordination (Munir et al., 2024). The strategic interventions should be tested on the basis of their emission-reduction potential, feasibility, cost-effectiveness, and adaptation to local conditions. Prioritization and implementation can be guided by evidence-based roadmaps, including those that summarize mitigation options for both the production and end-of-life phases. Policymakers should thus promote an enabling environment through standards, fiscal incentives, and government-private sector partnerships. It would be possible to balance Pakistan's development aspirations with its climate responsibilities only through an integrated approach that cuts across innovation, regulation, and circular practices.

Fig. 3. Concrete and Cement Sector

4. Discussion

Concrete is also important in advancing global urbanization by enabling the construction of necessary infrastructure and housing. Although it has a comparatively low environmental impact per unit of service, the growing global demand for concrete construction, driven by population growth and urbanization, poses a serious threat to the environment and people's health (Cerny et al., 2021). These include excessive water use, large-scale mining of raw materials, and the release of heavy metals and PM. This is particularly acute in Pakistan, where the urban population is expected to increase significantly in the next few decades. This will increase strain on construction resources and environmental impacts. This has made sustainable concrete use a national priority. To resolve the mentioned problems, policy and technological interventions in the construction sector need to be coordinated (Rockstrom et al., 2017; Dwivedi and Singh, 2025).

The shift to the circular economy model is generally viewed as a necessary measure towards sustainability in the construction industry (Antunes et al., 2021). This strategy focuses on the efficiency of resource use, the sustainability of materials management, and the recycling of materials throughout their life cycles. Nevertheless, despite the presence of other cementitious materials, their use remains minimal because the conventional cement industry is already mature and well established. The lack of awareness, time constraints, and disconnected supply chains are among the barriers that hinder the development of greenhouse gas (GHG) emissions reduction in the cement and concrete value chain. The lack of technical capacity and non-uniform enforcement of regulations are also complicating these issues in Pakistan (Uddin et al., 2023). The development of these barriers requires targeted capacity-building and institutional support. The environmental impact of concrete will only increase without the change of the system.

A complex approach is needed in order to alleviate these effects. This encompasses rigid regulatory systems, investment in research and development, and the introduction of new technologies, including low-clinker cement and carbon-capture technology incorporated into concrete products. Enhancing the efficiency of all steps in the construction process, such as design and material production, can result in significant reductions in GHG emissions (Sousa et al., 2023). Some of the measures with high potential are maximizing clinker and cement production, adding supplementary cementitious materials (SCMs), and improving construction and design. The implementation of these solutions in the Pakistani context should align with the country's industrial potential and infrastructure. To pilot and mainstream such innovations, there is a need to involve the private sector in collaboration with the government (Amir and Afzal, 2025). The key to long-term sustainability is to incorporate these practices into national construction standards.

The decarbonization of the cement and concrete industry addresses two interconnected problems (Habert et al., 2020). First, businesses should be able to identify and implement feasible decarbonization routes through technological innovations and operational efficiency, and search for new development opportunities. Second, they need to position themselves strategically within the broader sustainable construction value chain to be ready to meet future market needs. The cement manufacturers in Pakistan, which dominate the emerging market in South Asia, have a rare opportunity to spearhead this shift. This, however, requires shifting short-term profit models toward long-term sustainability planning. It is important to invest in workforce training and in adopting green technology. Policy activity alone cannot work without active involvement in the industry. Stakeholders need a common vision to enact systemic change.

Other ways to achieve energy efficiency include improved plant operations, modernized equipment, greater reliance on clinker substitutes, switching to cleaner fuels, and waste-heat recovery. The transition can be faster by setting minimum energy performance standards, such as requiring new cement plants to meet energy intensity standards that best available technologies can achieve, in addition to using financial incentives such as carbon pricing, low-interest loans, tax-free debt financing, and other fiscal policies. In a country like Pakistan, where power pricing and supply intermittency affect industrial productivity, these measures would confer both competitive advantage and lower emissions. There is also a need to increase the use of SCMs and industrial by-products, such as ground granulated blast-furnace slag and fly ash, with regulatory support. One of the advantages of these materials is that they minimize the need for cement and allow waste recycling. They have to be encouraged by the new building codes and quality assurance systems. National standards must be based on international best practices and account for local material availability (Sheheryar et al., 2021).

Finally, it will take bolder and more comprehensive approaches to green to net-zero operations in the sector, such as new construction techniques, new business models, and intersected collaborations. Even though traditional concrete is likely to continue being the most widespread construction type on the planet in the near future, it is impossible to avoid the global adoption of sustainable construction methods at the local and regional levels (Javed et al., 2024). This in Pakistan will imply adapting solutions to various climatic conditions, urban environments, and economies. The vision can only be achieved by human beings through transformative changes in current industry performance and the aggressive adoption of low-carbon policy frameworks. The key to success will lie in coordinating the government policy, industry action, and the community. Consumers and developers can be trained and sensitized through education and awareness to create demand for greener buildings. Such holistic efforts alone can help Pakistan establish resilient, low-carbon infrastructure for future generations.

5. Conclusion and Future Directions

The cement and concrete industry remains the mainstay of the built environment and economic growth in Pakistan, but it is also one of the most difficult sectors in terms of factory greenhouse gas emissions. The existing production rates are ever-increasing to meet the demands of urbanization and infrastructure, which puts pressure on the country's carbon budget. Although Pakistan has begun to recognize the need for climate action through national climate policies and its updated Nationally Determined Contributions, it will take more than efficiency improvements to achieve significant decarbonization in this sector. The transition necessitates a systematic shift across material innovation, circular design principles, supporting laws, and multi-stakeholder cooperation to align construction activities with long-term climate goals. The Pakistan plan should focus on three strategic directions going forward. To begin with, implementation of established low-carbon solutions, including reducing clinker use, using supplementary cementitious materials such as fly ash or rice husk ash, and enhancing kiln energy efficiency, should be phased in through policy requirements and financial incentives. Second, the carbonation potential of concrete during its natural service life needs to be recognized in national emissions inventories and incorporated into design schemes that increase CO_2 reabsorption without compromising sufficient structural performance. Third, a functioning circular economy for construction and demolition waste should be developed, with collection systems, recycling infrastructure, and building codes that encourage the recovery and reuse of these materials. Research is also required to develop alternative binders and low-carbon concrete formulations that are context-appropriate and suited to Pakistan's climatic and economic conditions. With all these measures integrated into a sensible, nationwide decarbonization plan and enhanced technical capacities along the value chain, Pakistan will be able to reduce the environmental impact of the construction boom and enable resilient, sustainable urban development.

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