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Review Article

Growth of Indian cement industry, its environment impact and emerging alternatives

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The present study provides a detailed review on growth of Indian cement industry, its environmental implications of cement production and its significant influence on the future trajectory of the Indian concrete industry. The Indian cement sector, a vital contributor to the nation's economy, faces a dual challenge of meeting the growing demand for construction materials while mitigating its environmental footprint. The study delves into the industry's current status as the world's second-largest cement producer and its impact on various sectors, including employment, GDP contribution, and dependence on real estate and infrastructure. The paper identifies key obstacles hindering the Indian concrete industry's full potential, such as a slowdown in real estate development, low industrial investment, regulatory changes, and constraints on resource extraction. Despite the industry's promising growth, the looming threats from emerging technologies and increasing environmental concerns, particularly related to greenhouse gas emissions, necessitate a strategic shift towards sustainability. A central focus of the research is the urgent need for the Indian concrete industry to address its environmental impact, specifically the 7% contribution to global greenhouse gas emissions. The study explores the industry's role in creating carbon-neutral concrete by 2050 and emphasizes the importance of collaboration with policymakers, financial institutions like the International Finance Corporation (IFC), and end users in achieving this ambitious goal. The study reveals the comprehensive resource for industry stakeholders, and researchers interested in understanding the environmental implications of cement production and charting a sustainable course for the future of the Indian concrete industry and emerging alternatives.

Keywords: Cement, Concrete, Greenhouse gases, Environment impact, Gross domestic product (GDP0

1 Introduction

1.1 Indian cement industry & its market potential

India is the second-largest cement producer in the world and accounted for over 8% of the global installed capacity[1, 2]. Of the total capacity, 98% lies with the private sector and the rest with the public sector. The top 20 companies account for around 70% of the total cement production in India[3]. As India has a high quantity and quality of limestone deposits throughout the country, the cement industry promises huge potential for growth. In 2022, the market size of India's cement industry reached 3.64 billion tonnes and is expected to touch 4.83 billion tonnes by 2028, exhibiting a CAGR of 4.94% during 2023-28[4]. India's cement production is expected to increase at a CAGR of 5.65% between 2016-22, driven by demands in roads, urban infrastructure and commercial real estate.

The consumption of cement in India is expected to grow at a CAGR of 5.68% from 2016 to 2022. India's cement production for FY24 is expected to grow by 7-8% driven by infrastructure-led investment and mass residential projects. The Indian cement sector's capacity is expected to expand at a compound annual growth rate (CAGR) of 4-5% over the four-year period up to the end of FY27[5]. It would thus begin the 2028 financial year at 715-725 MT/ year in installed capacity.

Cement consumption is expected to reach 450.78 million tonnes by the end of FY27. At present, the Installed capacity of cement in India is 570 MTPA with a production of 298 MTPA.

Cement production increased by 7.3% in February 2023 over February 2022. Its cumulative index increased by 9.7% during April-February, 2022-23 over the corresponding period of the previous year. The Cement sector has received good investments and support from the Government in the recent past.

Real estate sector received the highest value of PE/VC investments in Q1 (January-March) of 2023 at US$5 billion, registering an year-over-year 123% growth[6, 7]. In April 2023, the infrastructure and real estate asset class recorded US$ 3 billion in PE/VC

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investments, an 82% increase y-o-y and a 3% increase over March 2023. In 2022, PE/VC investments in real estate and infrastructure stood at US$ 5.81 billion across 71 deals and US$ 7.9 billion across 47 deals respectively[8].

PE/VC investments in real estate and infrastructure witnessed a sharp growth of 27%, at US$ 13.7 billion in December 2022 as compared to US$ 10.7 billion in December 2021[9], FDI inflows in the industry, related to the manufacturing of cement and gypsum products, reached US$ 5.49 billion between April 2000-March 2023. As per the Union Budget 2022-23, there was a higher allocation for infrastructure to the tune of US$ 26.74 billion in roads and US$ 18.84 billion in railways is likely to boost demand for cement[10].

Under the housing for all segment, 8 million households will be identified according Rs. 48,000 crore (US$ 6.44 billion) set aside for PM Awas Yojana. The government approved an outlay of Rs. 199,107 crore (US$ 26.74 billion) for the Ministry of Road Transport and Highways, and this step is likely to boost the demand for cement. Several government schemes such as MGNREGA, PM Garib Kalyan Rozgar Abhiyan and state-level schemes such as Matir Srisht (West Bengal) and public work schemes (Jharkhand) have aided demand.

In October 2021, Govt of India the 'PM Gati Shakti - National Master Plan (NMP)' for multimodal connectivity has been launched in india[11]. Gati Shakti will bring synergy to create a world-class, seamless multimodal transport network in India. This will boost the demand for cement in the future. Growth in Infrastructure and real estate sector, post-COVID-19 pandemic, is likely to augment the demand for cement in 2022. The industry is likely to add an ~8 MTPA capacity in cement production.

India's export of panel cement, clinkers, and asbestos cement products stood at US$ 682.32 million in FY23 while the imports were US$ 288.42 million. As per DGCIS, India's export of Portland cement, aluminous cement, slag cement, super sulphate cement and similar hydraulic cements stood at US$ 118.15 million in FY21. India exported cement to countries such as Sri Lanka, Nepal, the US, the UAE and Bangladesh[12-14].

The Government of India is strongly focused on infrastructure development to boost economic growth and is aiming for 100 smart cities[15-20]. The Government also intends to expand the capacity of railways and the facilities for handling and storage to ease the transportation of cement and reduce transportation cost. These measures would lead to an increased construction activity, thereby boosting cement demand. The future outlook of the cement sector looks on track with pandemic easing out.

In the next 10 years, India could become the main exporter of clinker and grey cement to the Middle East, Africa, and other developing nations of the world[21-23]. Cement plants near the ports, for instance the plants in Gujarat and Visakhapatnam, will have an added advantage for export and will logistically be well armed to face stiff competition from cement plants in the interior of the country. India's cement production capacity is expected to reach 550 MT by 2025[1, 24, 25]. The cement demand in India is estimated to touch 419.92 MT by FY27 driven by the expanding demand of different sectors, i.e., housing, commercial construction, and industrial construction.

1.2 Environmental concerns

In the present scenario, there are many problems faced by the cement industry, and the majority of the issues or hurdles in the development of the cement industry are related to environmental factors or environmental degradation due to this specific region, such as carbon (Greenhouse gas) emission, Freshwater consumption, Global warming Production of clinker, lack of limestone, Human Safety Aspects[26-28]. The history of cement goes back to the roman empire. The modern-day types of Cement. That is, Portland cement was first produced by a british stone mason, Joseph Aspdin, in 1824[29-31], who cooked cement in his kitchen. He heated a mixture of limestone and clay powder in his kitchen and ground the mixture into powder, creating Cement that hardens when mixed with water. The inventor gave the name Portland as it resembles a stone quarried on the Isle of portland. The first use of modern-day portland cement was in the tunnel construction in the Thames River in 1828. Manufacturing of cement involves various raw materials and processes. Each process is explained chemical reactions for the manufacture of Portland Cement. Cement is a greenish-grey coloured powder made of calcined mixtures of clay and limestone. However, As is known that limestone is one of the most basic raw materials required to make Cement[32, 33], and in due course of time, it is reducing at a very rapid rate, which leads to an ultimate increase in the demand for Cement. Hence the increased demand and less production will lead to rising prices.

2 Materials and Methods

On mixing of clay and limestone with water, it becomes a complex and robust building material. The manufacturing procedures of Portland cement are described below.

i Mixing of raw material[34]
ii Burning and cooling[35-37]
ii Grinding
iv Storage and packaging[38]

The process of making Cement is shown in Fig. 1, and the swchematic steps of various approaches are shown in Fig. 2

The impact of all the mentioned problems is in the existing market, and, most importantly, carbon emission is one of the most concerning factors that need to be kept in mind for a sustainable future. In today's world with emerging technology, carbon emissions in the cement industry have reduced considerably.

2.1 Environmental impact of cement production

Because the cement industry generates around 5-7% of worldwide anthropogenic CO_2 emissions, it is an essential sector for CO_2-emission reduction measures. CO_2 is emitted during the calcination of limestone, the combustion of fuels in the kiln, and the creation of electricity. The research examines the overall CO_2 emissions from the cement manufacturing process, including process and energy-related emissions. Currently, the majority of available data mainly contains process emissions. It also goes over CO_2 emission reduction strategies for the cement sector. In 1994, total carbon emissions from cement manufacturing were estimated to be 307 million metric tonnes of carbon (MtC), with process carbon emissions accounting for 160 MtC and energy use accounting for 147 MtC. In 1994, the top 10 cement-producing countries accounted for 63% of global cement-related carbon emissions. The average intensity of carbon dioxide emissions from total global cement production is 222 kgC/tonne of

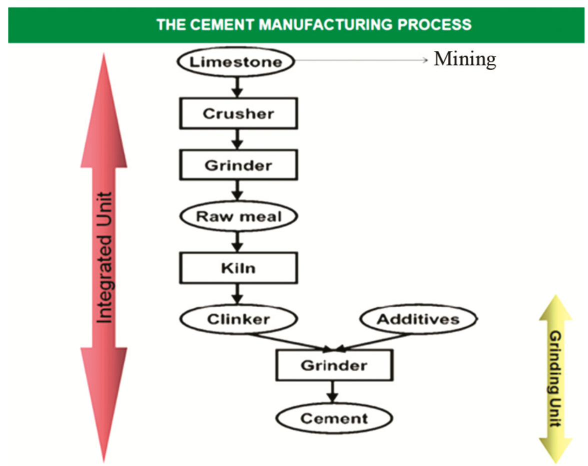

Fig. 1 — Process of manufacturing of cement[58].

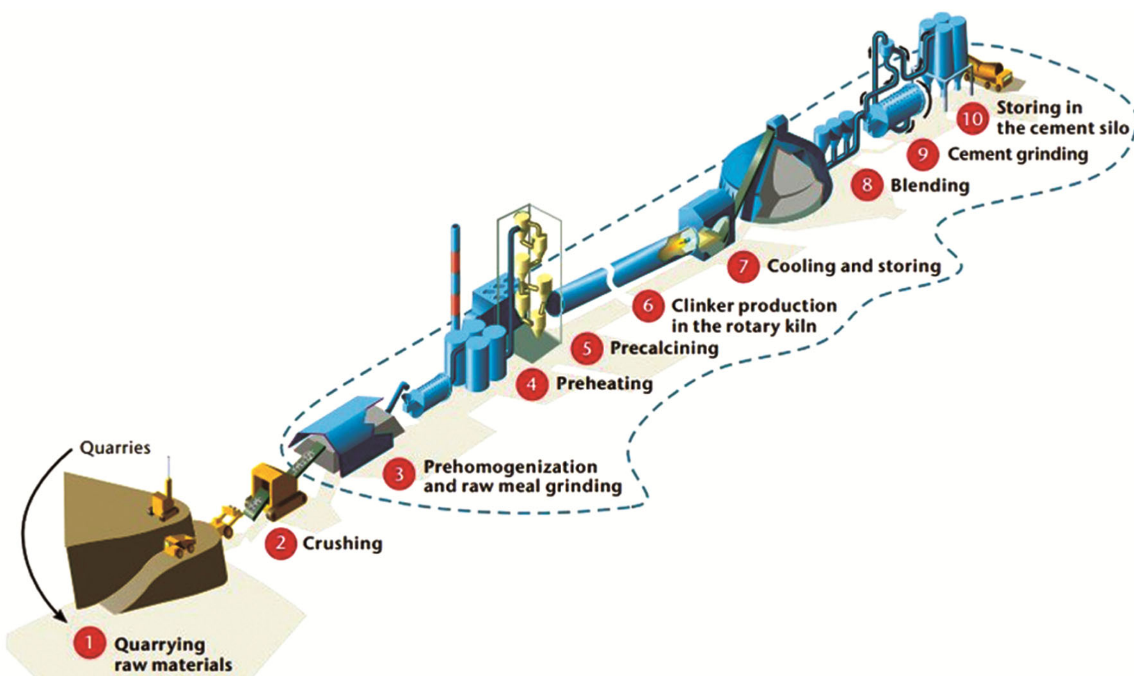

Fig. 2 — Schematic steps of various processes of cement production[58].

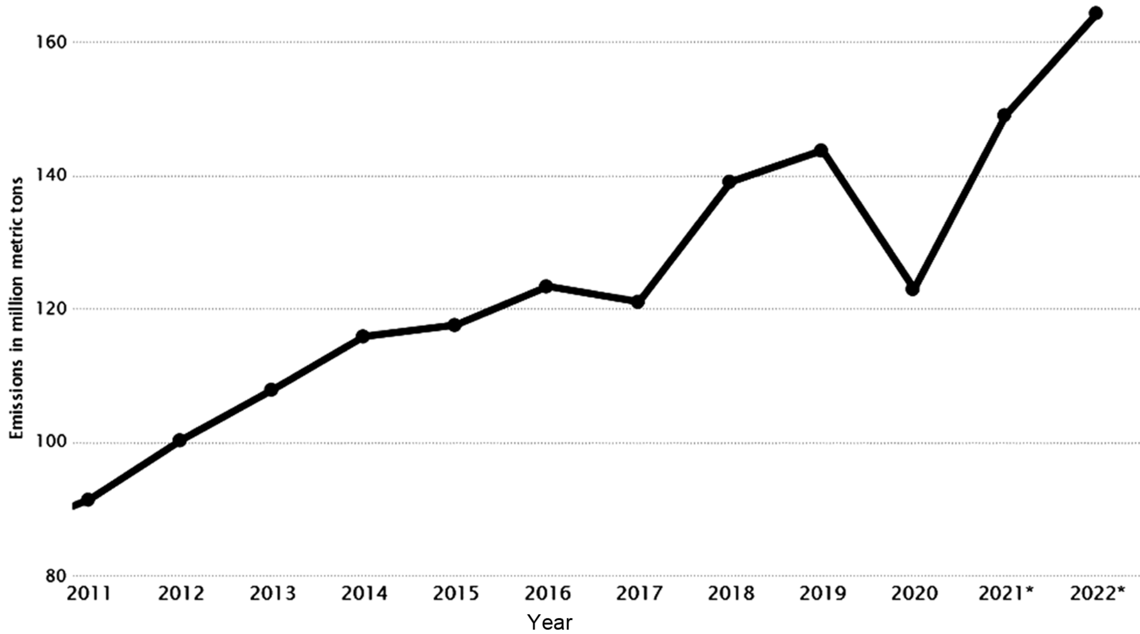

Fig. 3 — Carbon dioxide emissions from the manufacture of cement in India from 2011 to 2021.

Cement. Emission mitigation options include energy efficiency improvement, new processes, shift to low carbon fuels, application of waste fuels, increased use of additives in cement making, and, long turn, alternative Cement and CO_2 removal from flue gases in clinker kilns[39].

The increasing carbon dioxide emission from the manufacturers of cement in India from 2011 to 20210 is shown in Fig. 3.

2.2 Energy consumption in cement production

The electrical energy consumed in cement production is approximately 110 kWh/tonne. 30% of the electrical energy is used for raw material crushing and grinding, while around 40% of this energy is consumed for grinding clinker to cement powder[40].

Energy distributed among the various steps of the making of Cement:

Figure 4 shows the enormous amount of use of thermal energy (use of Coal). Furthermore, electricity is also used but significantly less than thermal energy in making Cement.

The future of Cement might be very bright or may have many zeros attached to it, but soon it will get replaced with cheaper, time-saving, and environmentally friendly concrete, also known as cement-free concrete. Yet, it has some hurdles lies in its usage; with time, more progress will be made, and Cement has a high rate of getting replaced in the future.

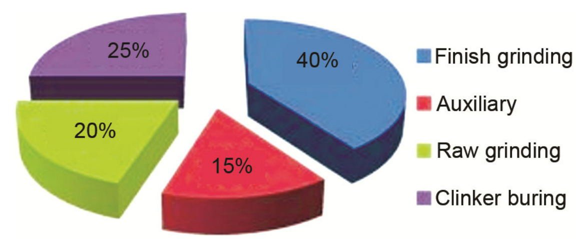

Fig. 4 — Energy demand distribution by process steps[54-56].

3 Results and Discussion

3.1 A Sustainable and healthy business module for cement industries

The cement industry is increasing its support for emissions reduction initiatives that go beyond the production stage. Additional opportunities for emissions reductions may be available by using a life-cycle approach and cooperating with all parties involved in the building value chain.

3.2 Optimizing the usage of concrete in construction

By balancing the lowest carbon choice with the best technical performance needed for the application, the efficient specification and use of concrete with a lean design may help reduce waste[67].

Optimizing concrete usage in construction goes beyond simply using less. It's about maximizing efficiency and minimizing waste throughout the entire lifecycle. Here are some key strategies:

- **Design optimization**: Utilizing Building Information Modeling (BIM) allows for precise 3D modeling, minimizing overdesign and material needs. Additionally, exploring modular or prefabricated elements reduces on-site cutting and waste.

- **Mix design optimization:** Tailoring concrete mix designs to specific project requirements, utilizing supplementary cementitious materials like fly ash and slag, and optimizing the water-cement ratio can significantly reduce the amount of cement needed while maintaining strength and durability.
- **Construction techniques:** Implementing efficient forming and shoring techniques minimize the need for concrete, while proper compaction ensures optimal utilization of the material poured. Additionally, exploring 3D printing technologies holds potential for precise material deposition and reduced waste.
- **Waste reduction and reuse:** Implementing proper waste management plans on construction sites, including segregation and recycling of concrete debris, minimizes landfilling and allows for the reuse of crushed concrete in future projects.
- **Utilizing sustainable alternatives:** Exploring alternative materials like geopolymer concrete or prefabricated elements with lower embodied carbon footprints can further reduce reliance on traditional concrete.

By adopting these optimization strategies, the construction industry can achieve significant environmental and economic benefits, paving the way for a more sustainable future.

3.3 Maximization of infrastructure and building design life

Maximizing Infrastructure and Building Design Life: Strategies for Long-Term Sustainability[41]

The longevity and durability of infrastructure and buildings are crucial aspects of sustainable development. Minimizing the need for frequent replacements leads to reduced resource consumption, lower environmental impact, and long-term cost savings. This article explores various strategies for maximizing the design life of infrastructure and buildings:

3.3.1 Material selection and quality control:

- **Utilizing Durable Materials:** Selecting high-quality, weather-resistant materials like reinforced concrete, engineered wood products, and corrosion-resistant metals for construction significantly increases the lifespan of structures.
- **Rigorous Quality Control:** Implementing strict quality control measures throughout the construction process ensures the proper use and installation of materials, minimizing the risk of premature deterioration.

3.3.2 Design for durability and resilience

- **Structural integrity:** Employing sound engineering principles and robust structural designs that can withstand anticipated loads and environmental factors is essential for long-term performance.
- **Consideration of future climate:** Integrating climate change projections into design considerations, including potential increases in extreme weather events, ensures structures are resilient to future environmental conditions.
- **Flexibility and adaptability:** Designing structures with the potential for future adaptations or alterations allows them to be repurposed for different uses over their lifespan, extending their overall value and reducing the need for demolition.

3.3.3 Maintenance and repair strategies

- **Preventative maintenance:** Implementing regular maintenance programs that include inspections, minor repairs, and cleaning significantly extends the lifespan of infrastructure and buildings by addressing issues early on and preventing them from escalating into more significant problems.
- **Life-cycle cost analysis:** Considering life-cycle costs during the design and construction phase is vital. This involves factoring in the initial investment and the long-term costs associated with maintenance, repairs, and potential replacements. Opting for materials and systems with lower long-term maintenance needs can lead to significant cost savings over the structure's lifespan.
- **Sustainable repair techniques:** Utilizing repair techniques that minimize environmental impact, such as using recycled materials or energy-efficient processes, contributes to the overall sustainability of the structure.

3.3.4 Digital technologies and monitoring:

- **Building information modeling (BIM):** Utilizing BIM throughout the design and construction process creates a digital model of the structure. This model can be used for ongoing facility management, efficiently identifying potential issues and implementing preventative maintenance strategies.[42, 43]
- **Sensor-based monitoring systems:** Implementing sensor-based monitoring systems allows for real-time data collection on structural health, environmental conditions, and potential problems. This data can be used to address issues and prevent premature deterioration proactively.

3.3.5 User behavior and operational practices

- **Occupancy awareness and education:** Educating occupants about proper building use and maintenance practices, such as responsible water and energy consumption, can significantly extend the lifespan of the building and its systems.
- **Waste management and recycling:** Implementing proper waste management and recycling practices within buildings helps prevent damage caused by improper waste disposal and contributes to the overall sustainability of the structure.

3.4 An encouragement of recycling and reuse:

Recycling and Reuse: A Green Path for the Indian Cement Industry

The Indian cement industry, while a powerhouse of infrastructure development, grapples with the environmental consequences of its production processes. One crucial path towards sustainability lies in embracing recycling and reuse practices**.** This not only minimizes environmental impact but also translates to economic benefits and resource efficiency.

3.4.1 Closing the loop: recycling opportunities

- **Wastewater reclamation:** Significant volumes of water are used in cement production. Implementing efficient water treatment systems allows for recycling and reusing wastewater within the process, reducing freshwater dependency and minimizing environmental impact.
- **Waste heat recovery:** Cement kilns generate substantial waste heat. Utilizing waste heat recovery systems allows capturing this heat and reintroducing it back into the production process, reducing reliance on fossil fuels and lowering energy consumption.
- **Fly ash utilization:** Fly ash, a byproduct of coal combustion in thermal power plants, poses a significant disposal challenge. The cement industry can utilize fly ash as a partial replacement for clinker in cement production. This reduces the need for virgin raw materials, promotes resource efficiency, and offers a sustainable solution for fly ash disposal.[44, 45]
- **Alternative fuel sources:** Waste materials like municipal solid waste, agricultural residues, and used tires can be processed and used as alternative fuels in cement kilns. This not only reduces dependence on fossil fuels but also offers a sustainable way to manage waste streams, contributing to a circular economy.[46, 47]

3.4.2 Beyond Waste: Innovative Reuse Strategies

- **Recycled packaging:** Cement bags are typically made of polypropylene or plastic. Encouraging the collection and reuse of these bags for packaging other materials or exploring biodegradable alternatives can significantly reduce plastic waste generation.
- **Reclaimed aggregates:** Construction and demolition waste generates a vast amount of concrete debris. Crushing and processing this debris can create recycled aggregates, potentially replacing virgin materials in concrete production. This reduces the demand for quarrying new resources and promotes resource efficiency.
- **Byproduct valorization:** Byproducts like clinker dust, a product of grinding clinker, can be utilized in other industries. Clinker dust can be used as a raw material in the production of lightweight aggregates or precast concrete products, maximizing resource utilization and minimizing waste.

3.4.3 Challenges and overcoming hurdles

While recycling and reuse offer immense potential, there are challenges to overcome:

- **Infrastructure investment:** Implementing efficient recycling and reuse technologies requires upfront investment. Government incentives and policies promoting such practices can encourage industry adoption.
- **Standardization and quality Control:** Recycled materials can exhibit variations in properties. Establishing clear standards and robust quality control measures is essential to ensure the performance and durability of cement produced with recycled content.
- **Market awareness:** Greater market awareness about the environmental benefits and performance of cement products utilizing recycled materials is crucial to drive demand and incentivize wider adoption.

3.5 A Collaborative Approach for Sustainable Growth

Embracing recycling and reuse necessitates collaboration between stakeholders:

- **Cement manufacturers:** Investing in necessary technologies, establishing robust recycling and reuse practices, and conducting research on utilizing new recycled materials are crucial steps for manufacturers.
- **Government:** Enacting supportive policies, providing financial incentives, and promoting research and development in recycling and reuse technologies are essential for government involvement.

- **Construction industry:** Architects, engineers, and construction companies can play a vital role by specifying the use of cement products with recycled content in their projects, driving market demand for sustainable solutions.

3.6 Environment sustainability factors for cement industries:

The Indian cement industry plays a pivotal role in the nation's infrastructure development, but its operations have a significant environmental impact. Accounting for approximately 13% of India's total industrial carbon dioxide emissions, the industry's ecological concerns are multifaceted.

Environmental Impact of the Indian Cement Industry

- **Air Pollution:** Cement production releases a range of air pollutants, including particulate matter (PM), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). These pollutants can cause respiratory problems, acid rain, and smog, posing serious health risks to the surrounding communities[48] .
- **Water pollution:** The cement manufacturing process generates wastewater laden with heavy metals, chemicals, and suspended solids. This wastewater can contaminate water sources, disrupting aquatic ecosystems and endangering water quality[1, 49].
- **Quarrying and land degradation:** Extracting limestone and other raw materials for cement production leads to deforestation, soil erosion, and loss of biodiversity. These activities degrade the natural environment and disrupt ecological balance [50, 51].
- **Greenhouse gas emissions:** Cement manufacturing is an energy-intensive process, contributing substantially to greenhouse gas emissions, particularly carbon dioxide (CO_2). CO_2 emissions from the cement industry are a major contributor to climate change, exacerbating global warming and its associated impacts[52, 53].

3.7 Strategies for environmental mitigation

The Indian cement industry is taking steps to address its environmental footprint. These strategies include:

- **Improving energy efficiency:** Cement plants are adopting energy-efficient technologies, such as waste heat recovery systems, kiln optimization, and alternative fuel exploration, to reduce fuel consumption and associated emissions.
- **Reducing clinker content:** Clinker, the primary component of cement, is a major source of CO_2 emissions. Cement plants are reducing their clinker content by using alternative cementitious materials, such as fly ash and slag, which have lower emissions profiles.
- **Adopting cleaner fuels:** Transitioning from traditional fossil fuels to cleaner alternatives, such as waste-derived fuels and renewable energy sources, can significantly reduce greenhouse gas emissions from cement production.
- **Implementing emission control technologies:** Installing air pollution control systems, such as electrostatic precipitators and bag filters, effectively capture and remove particulate matter and other pollutants from cement plant emissions.
- **Promoting sustainable construction practices:** Encouraging the use of eco-friendly construction materials, such as green concrete and recycled aggregates, can minimize the environmental impact of construction activities.

3.8 Moving towards a sustainable future

These efforts are helping to reduce the environmental impact of the Indian cement industry, but further progress is crucial. Continued innovation and investment in sustainable technologies, coupled with stricter environmental regulations and industry-wide cooperation, are essential to minimize the industry's environmental footprint and contribute to a more sustainable future. By embracing sustainable practices, the Indian cement industry can continue to support the nation's infrastructure needs while minimizing its environmental impact, ensuring a more harmonious relationship between industrial development and environmental protection.

3.9 Reduction of carbon emission levels

- **Improving energy efficiency:** deploying existing state-of-the-art technologies in new cement plants and retrofitting existing facilities to improve energy performance levels when economically viable.
- **Reducing the clinker-to-cement ratio:** increasing the use of blended materials and the market deployment of blended Cement to decrease the amount of clinker required per tonne of Cement or per cubic meter of concrete produced.
- **Using emerging and innovative technologies that:** contribute to the decarbonization of electricity generation by adopting EHR technologies to generate electricity from recovered thermal energy, which would otherwise be wasted, and support the adoption of renewable-based power generation technologies, such as solar thermal power. Integrate carbon capture into the cement manufacturing process for long-lasting storage or sequestration.

3.10 Switching to alternative fuels

Switching to alternative fuels that are less carbon intensive than conventional fuels delivers 0.9 $GtCO_2$ or 12% of the cumulative CO_2 emissions savings by 2050 globally in the 2DS compared to the RTS. This is equivalent to 42% of current direct CO_2 emissions of global cement production.

Coal is the fuel that is most widely used in cement production, representing 70% of the global cement thermal energy consumption. Oil and natural gas jointly contribute 24% to the thermal energy demand in global cement production, and biomass and waste (alternative fuels) contribute just above 5% of the global thermal energy use in the sector. After reviewing various articles regarding the same industry, product, and problems. It is found that a large gap between the human factor is to be kept in mind. Although the advancements are in favor of our environment and indirectly for human sustainability, working with those chemicals required to make the alternative for Cement can be very harmful and not easy to use.

Another gap we saw was that while keeping in mind the need for the friendly presence of Cement and concrete in our environment, we are ignoring the factor of what we will do with the residue of the waste that is made during the making process of Cement or after the Cement has served it time and has been old enough and un-useful now. Keeping in mind the market of this product is one of the biggest markets in the world, the need for the same will increase but will get broken down into different kinds of concrete for different uses, though the alternatives are still to be bought into use, we can clearly see there is a lot of space for a new yet equally viable product to come into use.

As we have seen, cement production is a very complex procedure requiring much energy. In the form of Thermal energy, which is derived from burning coal, resulting in the formation of a by-product known as fly ash. Moreover, electricity covers another half yet very minute use as compared to thermal energy[54].

3.11 Alternative construction binder

Cement alone contributes to approximately 96% of the carbon footprint of concrete, and 85% of the embodied energy[39].

The global average CO_2 emission per tonne of cement manufactured is estimated at approximately 0.83 tonnes[55]. meaning that the production of ordinary Portland cement accounts for 5% of the world-wide CO_2 emission. In case the construction industry continues with "business as usual", considering the expected increase in production, in 2050 cement industry alone will contribute to 24% of the total global CO_2 emission[56].

Such high share of CO_2 emission for just one industry will not be tolerated in the light of international activity to stabilise atmospheric pollution. Considering that any improvement in cement, due to its dominant share in carbon footprint, can lead to significant savings, most scientific efforts are presently focussing on the development of alternative binders for concrete (ABC). Many types of cement are already available on the market, especially when one considers that there is a limited combination of materials that are used in industrial production of cement. At the same time, the potential of using numerous other materials as partial or total cement replacement is studied, which could lead to creation of an enormous number of new binders that could at some point become available on the market. These new binders could significantly differ from classical cement, and could lead to different concrete properties on the macro scale. It is therefore of paramount importance to adopt a systematic approach when considering new binders, and to critically review opportunities but also challenges these new binders could bring to the engineering sector.

3.11.1 High volume supplementary cementitious materials (SCM)

Cement containing small amount of supplementary cementitious materials already makes up a large majority of currently produced cementitious binders. The global clinker factor was estimated at 0.77 in 2015, which means that at least 800 Mt of SCMs was used on a total of 4200 Mt cement produced in that year[57]. To create a more significant ecological effect, a push toward high-volume SCMs is inevitable[58]. and involves development of binders based on SCMs with small amount of cement used as an activator[59]. To meet a growing demand for cement and concrete, and considering limited supplies of high-quality SCMs, research is focussed on alternative SCMs such as red mud[60, 61], biomass ash[61-63], copper slag, calcined clays[64], limestone[65], and their engineering combinations[66]. The main challenge is to find materials that are available in significant quantities and that have favourable chemical and physical properties.

3.11.2 Limestone calcined clay cement (LCC)

Limestone is normally used as filler in cement industry; however, in recent years, it started to be used as a partial replacement for ordinary Portland cement[67]. One of the methods of activating reactivity of limestone is by adding reactive and silica-rich and alumina-rich materials, such as calcined clays[64,68,69]. In countries with an established ceramic industry substantial reserves of suitable clays are currently stockpiled as waste[23].

It can be observed that the clay most favourable for application in binder (kaolinite) is abundant mostly in regions where there is a massive need for construction, which makes the idea of unleashing this clay use potential highly justified. Currently, research efforts are focussed on pinpointing types of clays whose calcination would yield the most reactive material with an acceptable ecological footprint.

3.11.3 Geopolymeric binder

The geopolymer was first introduced by Davidovits in 1978. His work considerably shows that the adoption of the geopolymers could reduce the CO_2 emission caused due to cement industries[70].

The development of geopolymer concrete is an important step towards the production of environmentally friendly concrete[71].

Geopolymerization involves a chemical reaction between various alumino silicate material with alkali metal silicates under strongly alkaline conditions yielding polymer –Si-O-Al-O- bonds, which lead to geopolymers by poly-condensation.

3.12 Market sustainability of cement industries and the Indian economy

While the research paper is being written, It is seen that India is on the verge of getting its new budget for the year 2023-2024, and a much higher focus is on the budget of PM GATISHAKTI.

PM Gati Shakti will incorporate the infrastructure schemes of various Ministries and State Governments like Bharat Mala, Sagar Mala, inland waterways, dry/land ports, UDAN, etc. Economic Zones like textile clusters, pharmaceutical clusters, defence corridors, electronic parks, industrial corridors, fishing clusters, and Agri zones will be covered to improve connectivity & make Indian businesses more competitive.

So basically, focusing on the infrastructure development in India will surely raise the demand for Cement in the Indian market as more roads, buildings, etc will be built. This Might result In increasing prices of the same and a much higher demand for the year 2023, yet the future sustainability of the cement industry is predicted to be on an overall decline as many alternatives are taking place, which are far less in cost and are more environmentally friendly.

Market sustainability of the Indian concrete industry is based not only on government decisions but also it is based on various market factors such as usability, price of the product, quality of the product, etc. Traditional concrete (Cement) is easy to use, as the demand is high, the prices are also low, and it is available in various strength demographics, which can divide the quality of the same, providing average to good quality at different price points. Yet, with the emerging trend or awareness of carbon emission, carbon credits, etc., traditional concrete is now somewhat avoided. Whereas alternatives can be tough to use or hard to handle but the other advantages they provide, like considerable reductions in carbon emissions and freshwater consumption. Basically, sustainable use of resources is a much bigger problem that is being solved by them.

3.13 Preference for alternatives to cement

Most of the population on which the survey was conducted was in favour of the statement that alternatives to cement are the future of the Indian concrete industry. The cement industry is a major contributor to global greenhouse gas emissions, accounting for about 8% of total emissions. This is due to the energy-intensive process of clinker production, which releases carbon dioxide (CO_2) as a byproduct. In addition, the cement industry also consumes large amounts of raw materials, including limestone, sand, and clay, which can lead to environmental damage such as deforestation and soil erosion. There are a number of alternatives to traditional Portland cement that can help to reduce the environmental impact of the cement industry. These alternatives include:

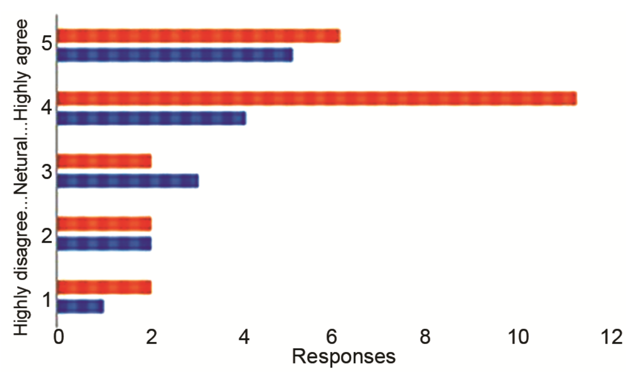

Fig. 5 — Agreeability of people to use alternatives of cement on the basis of research conducted.

- **Geopolymers:** Geopolymers are made from fly ash, a waste product from coal-fired power plants, and alkaline activators such as sodium hydroxide or potassium hydroxide. Geopolymers have been shown to have similar strength and durability to Portland cement, but they have a much lower carbon footprint[72-74].
- **Calcium sulfoaluminate (CSA) cement:** CSA cement is made from calcium sulfate and aluminum silicate. It has a lower clinker content than Portland cement, which means that it produces less CO_2 emissions. CSA cement is also more resistant to sulfate attack, making it a good choice for use in applications where concrete is exposed to seawater or other aggressive chemicals[75-78].
- **Calcined clays:** Calcined clays are made from clay that has been heated to a high temperature to remove water and other impurities. Calcined clays can be used as a partial replacement for clinker in Portland cement, which can reduce CO_2 emissions by up to 20%.
- **Limestone calcined clays (LC2):** LC2 is a type of calcined clay that is made from a mixture of limestone and clay. It has been shown to have similar strength and durability to Portland cement, and it can be used as a complete replacement for clinker. LC2 has the potential to reduce CO_2 emissions by up to 70%[79-81].

The cost of these alternatives varies depending on the specific material and the manufacturing process. However, in general, they are more expensive than Portland cement. This is due to the higher cost of raw materials and the more complex manufacturing process. Despite the higher cost, there are a number of factors that are driving the adoption of alternative cements. These factors include:

- **Increasing environmental regulations:** Governments around the world are introducing stricter regulations to reduce greenhouse gas emissions. This is making it more expensive to produce Portland cement, and it is making alternative cements more attractive.
- **Demand for sustainable construction:** There is a growing demand for sustainable construction materials. This is driven by a number of factors, including consumer demand for environmentally friendly products and government initiatives to promote green building.
- **Advances in technology:** There have been significant advances in the technology for producing alternative cements. This has made these materials more cost-competitive and has improved their performance.

As a result of these factors, the market for alternative cements is expected to grow rapidly in the coming years. This could have a significant impact on the cement industry, as it could lead to a reduction in the demand for Portland cement.

The Table 1 summarizes the alternatives to traditional Portland cement and their associated costs:

3.15 Porter's five force model analysis on the Indian concrete industry and its future

Porter's Five Forces is a strategic framework used to analyse the competitive dynamics of an industry. It examines five key factors that influence an industry's competitive intensity and attractiveness.

Threat of new entrants

The Indian concrete industry has a moderate to high barrier for new entrants. Factors such as high initial capital investment, economies of scale, distribution networks, and access to raw materials can deter new players from entering the market. However, the growth potential of the Indian construction sector and the increasing demand for sustainable and innovative construction materials might attract new entrants. Overall, the threat of new entrants can be considered moderate.

Bargaining power of suppliers

The bargaining power of suppliers in the Indian concrete industry can vary depending on the specific materials used in concrete production. Cement and aggregates are the primary raw materials. The cement industry in India is dominated by a few prominent players, which can give them significant bargaining power. However, various sources of aggregates could mitigate supplier power to some extent. The industry's ability to switch between suppliers and the availability of substitutes can moderate supplier power.

Bargaining power of buyers

Buyer power in the Indian concrete industry can be influenced by factors such as the concentration of buyers, the significance of concrete in construction projects, and the availability of alternative construction materials. If buyers are concentrated and can switch between suppliers easily, they might have higher bargaining power. However, the importance of quality

Table 1 — Approximate cost of alternative binders.

Alternative	Cost ($ per ton)
Geopolymers	120-150
CSA cement	150-200
Calcined clays	100-130
LC2	70-100

and reliability in construction projects limits buyer power.

Threat of substitutes

The threat of substitutes in the Indian concrete industry might be moderate. While alternative construction materials like steel, wood, and composites exist, concrete remains a fundamental material in Construction due to its versatility, cost-effectiveness, and durability. However, innovations in sustainable construction practices and the development of new materials that could replace traditional concrete could impact the industry's future.

Competitive rivalry

The competitive rivalry in the Indian concrete industry is likely to be high. The industry needs to be more cohesive, with numerous players, including large cement manufacturers, smaller concrete producers, and construction companies producing their own concrete. Price competition, differentiation through product quality, technological advancements, and sustainability initiatives could all contribute to intense rivalry. The industry's growth prospects and the increasing demand for infrastructure and real estate development will further fuel competition.

3.21 Future outlook

The future of the Indian concrete industry is promising yet challenging. The industry is poised for growth due to ongoing urbanization, infrastructure development, and increasing construction activities. However the Indian concrete industry faces a challenging but promising future. The business is ready for development because of progressing urbanization, framework improvement, and expanding development exercises.

Its future may be influenced by the following:

- **Sustainability:** The business's natural effect and the developing interest in manageable development practices could prompt advancements in substantial creation, including elective materials and further developed assembly processes.
- **Technology:** Taking on trend-setting innovations like 3D printing, self-mending concrete, and canny development practices could change how cement is utilized and created. Regulations: Rigid natural guidelines and quality principles could affect creation processes, expecting organizations to put resources into cleaner, more effective advances.
- **Investing in infrastructure:** Demand for concrete products will be driven by government policies and investments in infrastructure projects.
- **Market union:** The business could see a combination of additional huge players getting more modest ones to fortify their market presence and improve economies of scale. Innovation: Ceaseless innovative work endeavors can prompt the disclosure of new substantial definitions with further developed properties and applications.

4 Conclusion

By analysing the data collected through the deep survey and various analysis tools, it can be concluded that there is a need for more alternative products as new methods and techniques are coming up, like reusing asphalt mixture yet using environmentally precious materials is harming the environment in various ways like air quality, water quality, Carbon emission, etc. thus using cement alternatives like fly ash based cement-free concrete and steel slag based concrete. It is and will be proven best for the needs of the future.

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