CEMENTING THE TRANSITION

The Role of Energy Efficiency in Decarbonising India's Cement Sector

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Contents

List of abbreviations

AFRM	Alternative Fuels and Raw Material
BEE	Bureau of Energy Efficiency
CC	Composite Cement
CCC	Carbon Credit Certificates
CCTS	Carbon Credit Trading Scheme
CCUS	Carbon Capture Utilisation and Storage
CII	Confederation of Indian Industry
CMA	Cement Manufacturers Association
EAC	Electric Arc Calciners
EE	Energy Efficiency
GBFS	Granulated Blast Furnace Slag
GH_2	Green Hydrogen
HHV	Higher Heating Value
HPGR	High Pressure Grinding Rollers
MSW	Municipal Solid Waste
MTPA	Million Tonnes per Annum
OPC	Ordinary Portland Cement
PAT	Perform, Achieve and Trade
PPC	Portland Pozzolana Cement
RDF	Refuse Derived Fuel
SCM	Supplementary Cementitious Materials
SEC	Specific Energy Consumption
VAM	Vapour Absorption Mechanisms
VFD	Variable Frequency Drives
VRM	Vertical Roller Mills
WHRS	Waste Heat Recovery Systems

Executive summary

As of 2024-2025, India produced over 9 per cent of the world's cement, with a total production capacity of 622 million tonne per annum (MTPA); the total production was 453 MTPA. According to S&P Global, the capital market company, between FY2026-2028, the cement industry plans to expand its total capacity by an estimated 160 to 170 MTPA.

The NITI Aayog's data shows that the current average emission intensity of the cement sector is around 0.63 tonne CO_2 equivalent/tonne of cement, resulting in roughly 246 million tonne of CO_2 emissions annually. If current practices continue unchanged, these emissions could potentially reach three times their current level by 2050.

Several roadmaps for emission reduction in the cement sector, with varying levels of ambition, have been developed by think tanks and research organisations, including Centre for Science and Environment (CSE). The most recent among these is the Roadmap for Cement Sector Decarbonisation, released by the NITI Aayog in January 2026. The pathways for decarbonisation of the sector in the near- and long-term are clear. Among them, energy efficiency is one which has been extensively adopted by the sector over the past decade. There remains some scope which could contribute to additional emission reductions in the near term. The scope may expand further in the future based upon the emergence of new and innovative energy-efficiency technologies.

A long list of technologies and practices are available in the sector to improve energy efficiency. This study undertaken by CSE attempts to highlight the major ones, most of which are commercially available and offer the highest emission reduction potential among the available options. The report showcases nine key energy-efficiency technologies at different levels of adoption in the sector. It finds that, if fully adopted, these technologies could reduce the sector's average emission intensity by 0.0138–0.0185 tCO_2/t cement or 2.19–2.94 per cent and reduce the overall sectoral emissions, equivalent to 6.26–8.39 MT CO_2 emission annually.

The study also outlines the costs of adopting these technologies individually, as well as the overall cost that the sector would need to bear for their implementation. These are tentative estimates and actual costs may vary on a case-by-case basis.

The findings also indicate that the targets assigned to the sector under the CCTS for the years 2025-26 and 2026-27 can largely be met through the adoption of the listed energy-efficiency technologies. Currently, the average reduction in emission intensity over the two years is around 2.98 per cent with average emission intensity reduction target of 0.0177 tCO_2/t (8.02 MTPA). This study shows that a large share of the target is still achievable through adoption of energy efficiency, and therefore is important in highlighting the immediate actions the sector can take to meet CCTS targets and contribute to the country's NDC goals. At the same time, it is clear that further and more substantial emission reduction will require the use of future transformative technologies in energy efficiency, including alternate fuels, replacement of limestone, increasing share of blended cements and adopting CCUS for residual emissions.

Introduction

Pursuing climate goals outlined under the Paris Agreement will require economies around the world to pursue deep decarbonisation in high carbon-emitting industrial sectors such as steel, cement, aluminium, chemicals and refining. These sectors contribute significantly to global greenhouse gas emissions, both through the energy needed for production and emissions generated through the production process itself.

As a fast-growing emerging economy, India faces acute challenges in balancing rapid economic growth, infrastructure development and energy security, with the need to decarbonise its growing economy. Hard-to-abate industrial sectors account for a significant portion of the country's emissions. As India continues to expand its manufacturing capacity across sectors to meet its growing demand, it is critical to ensure that the pathway for expansion is non-conventional and low carbon. Despite India having already improved its emissions intensity of GDP by 36 per cent since 2005,[1] continuing down this path and achieving long-term success will require a substantial acceleration in the pace at which it can decarbonise its existing and upcoming capacity of hard-to-abate industrial sectors.

Reducing the use of energy is one of the quickest and cost-effective ways to decarbonise industry. There is great potential to lower fuel use and emissions through improvements in the energy efficiency of industrial processes, equipment and energy systems.

In 2012, India brought a market-based scheme to support energy-efficiency improvements, called the Perform, Achieve and Trade (PAT) programme. It was based on market mechanisms, setting limits on specific energy consumption (SEC) for energy-intensive industries. Under PAT Cycle 1, SEC targets were assigned for 478 facilities across eight industry sectors. The cycle saved 8.67 MTOE energy across all facilities, exceeding PAT's energy saving target and resulting in an approximate reduction of 31 million tonne CO_2 emissions.[2] As of 2021, PAT cycles had resulted in enhanced development, with cumulative energy savings of about 17 MTOE and nearly 87 million tonne of CO_2 annually.[3] While the scheme has faced criticism regarding the ambition of its targets, overachievement by obligated entities and excess energy certificates, it has nevertheless played a crucial role in initiating an organised ecosystem around energy efficiency. It has also encouraged industries to take initiatives towards implementing energy efficiency in their processes.

The cement industry has been one of the main contributors to the energy reduction achieved under the PAT scheme. It had a share of 12.19 percent of the total energy savings achieved in PAT cycle 1.[4] One thing this clearly illustrates is that majority of energy efficiency measures are both technically feasible and economically viable in the cement sector. Based on experience gathered in successive PAT cycles, India is advancing towards a more comprehensive carbon market framework through implementation of its Carbon Credit Trading Scheme (CCTS). The CCTS will create a national carbon market that will allow for the trading of carbon credits based on emissions reductions achieved. This is a significant change from an energy intensity-based regulatory system to an emissions-based regulatory system in which carbon pricing signals are envisioned to serve as the foundation for driving industrial decarbonisation. The success of this type of system in the near future will hinge heavily on the existence of cost-effective mitigation options, such as energy efficiency measures. The broader adoption of energy efficiency measures, especially future technologies, are constrained by barriers such as lack of accessible information, lack of multiple options for technology suppliers, risk perception regarding operational challenges and economic viability. Addressing these barriers is essential to fully unlock the sector's efficiency potential.

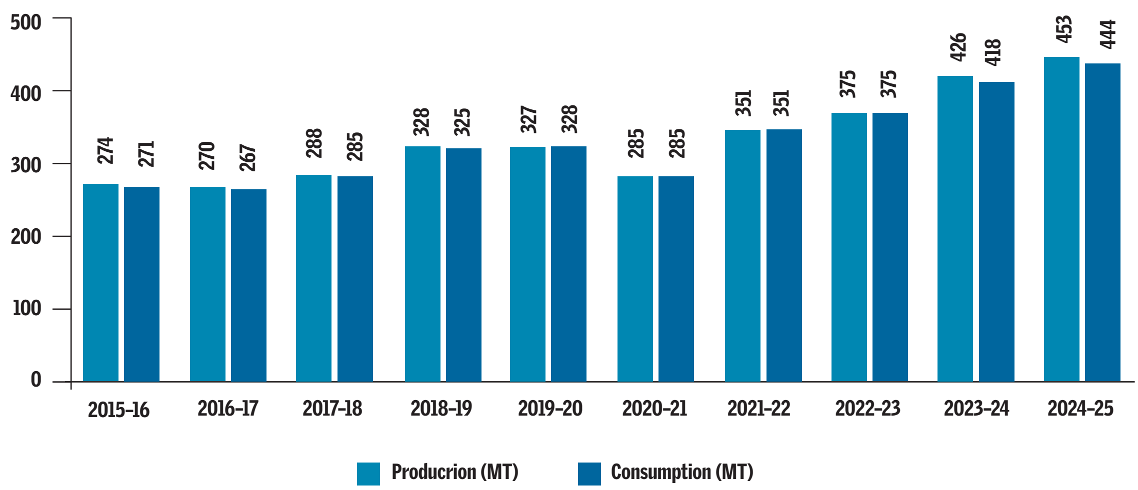
This report focuses on the role of energy efficiency as an important lever for industrial decarbonisation and specifically focuses at the cement manufacturing sector to measure the potential and scope of energy efficiency as a tool for reducing greenhouse gas (GHG) emissions. The analysis examines current and emerging energy efficiency measures and technologies to determine what role they can play in achieving near and future emission reduction, thereby contributing to the country's climate goals. The purpose of this research is to present a clear picture with the required details and evidence to equip policymakers and industry to accelerate low-carbon decision-making through energy efficiency in India's cement sector.

1
SECTOR PROFILE

India is the second-largest cement producer in the world, accounting for more than 8 per cent of the global production. As of 2024–25, India's cement production capacity stood at 453 million tonnes per annum (MTPA), with a total installed capacity of 622 MTPA.[5] Cement production grew by 6.3 per cent in 2024–25 compared to 2023–24. The sector is expected to grow at a robust rate, with projected addition of 160–170 Mt capacity between fiscal years 2026 and 2028,[6] with the possibility of reaching 600–700 MTPA by 2030.

The sector has a substantial footprint in the country. The industry is comprised of 160 large cement plants, 130 grinding units, 62 mini-cement plants and five clinkerisation units.[7] The projected installed capacity is expected to reach 850 MTPA by 2030.[8]

Graph 1: Production and Consumption of Cement in India between 2015–16 to 2024–25 (Million Tonnes)



Source : 1. https://infomericstorage.blob.core.windows.net/uploads/Cement_Industry_Report_May2023_f9effc5c9c.pdf
2. https://www.cemnet.com/News/story/178599/indian-cement-demand-slowed-in-2024-but-will-rebound.html
3. https://www.ibef.org/industry/cement-india/infographic

Due to rising demand in India, over 40 per cent of India's current installed capacity in the cement sector was commissioned over the last decade.[9] As a result, a major part of the sector has incorporated advanced plant machinery. The country has nearly transitioned to water efficient dry process technology. Owing to the abundant availability of supplementary cementitious materials (SCMs), such as fly ash and blast furnace slag, India maintains a relatively low clinker-to-cement ratio of approximately 0.7, compared to the global ratio of 0.76.[10] However, there is still scope for further improvement in bringing down the clinker factor in the future.

Figure 1: Distribution of cement manufacturing units in India

160	**130**	**62**	**5**
Large cement plants	Grinding units	Mini cement plants	Clinkerisation units

Source: https://www.dpiit.gov.in/static/uploads/2026/03/863a5fef349d79a1bba316c4b51eaacb.pdf

About 40 per cent of India's installed capacity was commissioned over the last ten years due to sustained demand growth. This has led to the adoption of state-of-the-art plant equipment and an extensive shift from wet-process to dry-process technology. Dry kilns are significantly more energy efficient, as compared to wet kiln processes.

India currently has an abundant supply of SCMs, including fly ash from thermal power plants and granulated blast furnace slag (GBFS) produced by the steel industry. In the current scenario, this is an advantage for India's cement sector and has enabled India to achieve a low clinker-to-cement ratio of 68 per cent to 70 per cent (0.68–0.70),[11] compared to the global average of 76 per cent (0.76).[12] A lower clinker ratio is important as the production of clinker is the most carbon-intensive part of the cement manufacturing process. Therefore, by incorporating SCMs into the final product, the amount of clinker needed to produce per tonne of cement is reduced, resulting in the overall reduction of CO_2 emission.

2
EMISSIONS

Sources and role of composition

Cement production is inherently carbon-intensive, and its emissions profile is structurally different from that of most other heavy industries. In the traditional cement production technique, about 60–65 per cent of the emissions come from a process called calcination, in which limestone is heated up to 1400°C and converted into clinker ($CaCO_3 \rightarrow CaO + CO_2$). Carbon emissions during this process cannot be eliminated through conventional fuel switching or energy efficiency improvements alone and account for approximately 50–56 per cent of total emissions from the sector. Apart from process emissions, 30–35 per cent of emissions are derived from the burning of fossil fuels (primarily coal), and 5–10 per cent are due to indirect emissions from grid electricity usage. By reducing the percentage of lime in cement through the introduction of SCMs, blended cements can reduce their carbon footprint. India produces different types of cement, including Portland Pozzolana Cement (PPC), Ordinary Portland Cement (OPC) and composite cement (CC). Each category has a different emissions footprint. For example, OPC has a clinker usage of 90–95 per cent,[13] as compared to composite cement (CC), with a clinker proportion between 35–65 per cent,[14] making it less emissions-intensive than OPC. Energy-related emissions from different processes, mainly grinding, mixing and fuel combustion in kilns, are the other major contributors. Since the Indian cement sector is heavily dependent on coal and pet coke, higher energy consumption generally results in higher emissions.

Current intensity and trajectory

The Niti Ayog roadmap for the cement sector shows the current average emission intensity of the sector in India stands at **0.63** tonnes of CO_2 per tonne of cement, which is equivalent to **246 Mt** of CO_2 equivalent per year.[15] The roadmap shows that, without intervention, the cumulative emissions from the industry could triple by 2050 as demand grows.[16] A low carbon trajectory is therefore required for the sector to be able to contribute to India's Paris Agreement commitments to reduce emission intensity by 47 per cent by 2035 and achieve net-zero by 2070.[17]

3 DECARBONISATION PATHWAYS

As the industry is witnessing rapid growth to meet demand, a sustainable shift is desired to limit its carbon footprint. CSE had put out a pathway that showcased ambition in the possibility of emission reduction in the sector. Published in 2023, the report envisaged a target of carbon emission intensity below 0.4 tonnes by the 2050.[18] The levers or pathways proposed in CSE's is closely similar to the roadmaps envisioned by NITI Ayog with an effective emission intensity target of 0.09–0.13 tCO_2e per tonne of cement by 2070.[19]

Overview of pathways

India's cement sector can be decarbonised through broadly classified pathways, supported by an enabling ecosystem of policies and financial incentives. A multi-pronged approach is required, and the key pathways are:

Energy Efficiency (EE): This pathway reduces the thermal and electrical energy consumption per unit of output through improved process and equipment performance. This is the most readily available pathway for action and can be implemented in existing plants in India.

Alternative fuels and energy sources: This involves the replacement of fossil fuels, specifically coal and pet coke, with sources such as biomass, refuse-derived fuels (RDF) and other emerging low-carbon fuels to minimise fuel-related emissions and further enable circularity practices. While biomass and RDF are available fuel options for reducing emissions, alternative fuels such as Green Hydrogen (GH_2) and other green fuels need more research and adoption. Electrifying kilns, powered by renewable energy sources, offers another pathway to reduce dependence on carbon-emitting fuels. However, this technology is still in its early stages and faces challenges in terms of scale, cost, and technical readiness. Further research and development are needed before it can be adopted at a commercial or industrial scale. Moreover, round-the-clock renewable energy could play a key role in decarbonising electrical energy usage in a cement plant.

Clinker factor reduction: This process requires reducing of the proportion of clinker in the total cement product by increasing the volume of supplementary cementitious materials (SCMs), such as fly ash, Granulated Blast Furnace Slag (GBFS) and limestone calcined clay. Increased use of SCMs can substantially reduce the emission intensity. According to the previous estimates, a 40 per cent SCM mix in PPC can bring down the emission factor to 0.5 tonne while a 45 per cent SCM mix can further reduce it to 0.45 tonne of CO_2 per tonne of cement.[20]

Carbon Capture Utilisation and Storage (CCUS): In the cement industry, this is the only option that addresses process emissions. Carbon capture and storage technology, with a potential capture rate of up to 80 per cent, will be necessary to achieve net zero in the cement sector, as the world has yet to invent limestone-free cement. The emissions produced by the chemical reaction during the calcination process cannot be eliminated through energy efficiency improvements or fuel replacement alone.

Role of energy efficiency in decarbonising the cement sector in India

Energy efficiency plays a vital role in India's cement sector decarbonisation for two reasons. It helps mitigate energy-related emissions as well as reduce production costs. Producing 1 tonne of cement generally requires between 3,000–3,500 MJ of thermal energy and 80–130 kWh of electrical energy, depending on the plant technology used and the age of the manufacturing facility.[21]

The Indian cement industry has seen significant reductions in Specific Energy Consumption (SEC) over the last 20 years, driven by a combination of factors, including the Bureau of Energy Efficiency's (BEE) Perform, Achieve and Trade (PAT) scheme, which provided the necessary regulatory push. Despite these advances, there remains significant potential for further energy savings through reductions in Specific Energy Consumption (SEC), defined as the thermal and electrical energy consumed per tonne of cement, in the Indian cement industry. According to the Confederation of Indian Industry's (CII) report,[22] as of 2025, the average electrical SEC for the Indian cement industry is 73 kWh/t production of cement production and 50 kWh/t of clinker. The top ten plants by manufacturing capacity operate at less than 67 kWh/t of cement, showing a significant difference in the adoption of energy-efficient technologies between small and large plant operators. The average thermal SEC is 7,40,000 kcal/t of clinker. The difference between large and small plants shows a gap of 50,000–60,000 kcal/t of clinker, marking a 6.7–8.1 per cent difference. While the Indian cement sector has substantially reduced SEC during the last 20 years, the current gap between average plant performance and the best achievable plant performance remains substantial. This indicates that larger companies have readily invested in emission reduction processes, while scope for improvement still exists among smaller companies.

4
METHODOLOGY

This report analyses the CO_2 emission reduction potential of energy efficiency technologies in the Indian cement sector. It uses sources such as published energy benchmarking data, peer-reviewed articles and industry performance metrics to calculate potential reductions in emissions resulting from improvements in thermal and electrical energy usage at cement manufacturing plants. These data are cross-referenced by industry experts. The report covers two categories of emissions related to energy use—thermal emissions from the combustion (burning) of fossil fuels to produce the heat required to operate kilns, and emissions associated with electricity generated from captive power plants for cement grinding, mixing and auxiliary processes. Emissions related to calcination are not considered in this report, as they cannot be addressed through energy efficiency improvements. Rather, they are included for reference purposes only. Quantitative estimates are based on 453 million tonnes of cement produced in India in 2024–25. The report considers both current and emerging technologies, with current technologies being commercially available and having documented performance based on their current adoption by the industry, and emerging technologies being at the pre-commercial or early stage of demonstration but not yet widely implemented in India.

Key assumptions

For the calculation of emissions, a few assumptions are made. The average clinker factor in India[23] is considered to be 0.70 tonne of clinker per tonne of cement. This factor is applied only to technologies where savings are expressed per tonne of clinker. The thermal emission factor for cement clinkerisation is considered to be 0.396 g CO_2/kCal, which is the default industry factor for coal combustion.[24] For calculating the electrical emission factor, a coal-based captive power plant is considered as the baseline, at 0.961 kg CO_2/kWh, as per Central Electricity Authority (2026).[25] For the calculation of the annual cumulative emissions of the sector, an annual production capacity of 453 Mt is considered.

Table 1: Basis of estimation

Parameter	Value
Sector annual production	453 Mt/year
Average clinker factor in India	0.70 t clinker/t cement
Thermal emission factor of cement clinkerisation unit	0.396 g CO_2/kCal
Electrical emission factor from coal based captive power plant	0.961 kg CO_2/kWh

Limitations

The following limitations apply to the quantitative estimates in this report:

- Range estimates reflect energy efficiency scope from published literatures and stakeholder discussion. The real number may vary.
- The electrical emission factor (0.961 kg CO_2/kWh) reflects India's current grid intensity and will change with adoption of fuel mix.
- The equipment capital costs are tentative. The actual figures may vary depending on factors, including the age of manufacturing unit, exchange rates and market conditions.

5 KEY ENERGY EFFICIENCY TECHNOLOGIES

The cement sector in India has shown proactive adoption of energy efficiency technologies and measures.[26] The industry has consistently invested in the modernisation and adoption of the latest technologies to lower its carbon footprint. Among the wide range of energy efficiency technologies available and adopted by the sector, nine technologies are highlighted and discussed in this report, based on their comparatively high potential for emission reduction amongst all.

Thermal energy efficiency technologies

Waste Heat Recovery System (WHRS)

Scope of energy savings: 30–35 kWh/t clinker | Sector-wide CO_2 reduction scope: 1.37–1.60 Mt

Waste Heat Recovery Systems (WHRS) in cement plants are a major part of energy-efficiency systems, as they recover heat that would otherwise be wasted through the exhaust from kilns. These systems convert waste heat into useful forms of energy for cement plant operations, resulting in reduced emissions.

In dry-process cement plants, heat energy input to the kiln is wasted through preheater and cooler exhaust gases. These gases can be converted into steam by Higher Heating Value (HHV) boiler systems to drive an electricity-generation turbine set.[27] From an efficiency perspective, WHRS enables cement plants to produce up to 25–30 per cent[28] of the electrical energy required by the plant by recapturing exhaust heat that would otherwise be released into the atmosphere. WHRS not only helps reduce carbon emissions but also lowers fuel consumption, thereby reducing overall manufacturing costs. This system requires a minimal amount of additional physical space adjacent to the preheaters and coolers. In India, WHRS are installed in about 80–90 per cent cement manufacturing plants. Adopting the technology provides a scope for reducing emission by 0.0030–0.0035 tCO_2/t of cement. Factoring in the current adoption rate, WHRS has the potential to further reduce emissions by 1.37–1.6 $MtCO_2$ in the Indian cement sector.

Low-temperature WHR

Scope of energy savings: 6–7 kWh/t clinker | Sector-wide CO_2 reduction scope: 1.74–1.92 Mt

Conventional WHRS capture high-grade heat from preheater and cooler exhaust gases, but low-temperature residual gases at the end of the recovery chain are still discharged into the atmosphere without energy capture. These typically include low-grade exhaust gases from the cold-end vent of the grate cooler. Low-temperature WHR systems use Organic Rankine Cycle (ORC) or Kalina cycle technology to intercept this residual heat. The collected heat has an estimated energy saving potential of 6–7 kWh/t of clinker.[29] This is an emerging technology, and currently its industry adoption is very low (0–2 per cent). Adoption of the technology is estimated to reduce emissions by 0.0038–0.0042 tCO_2 per tonne of cement. Although capital-intensive, these systems expand the scope of heat recovery beyond traditional WHRS and can significantly improve overall plant energy performance when integrated effectively. Factoring in the current adoption rate, this technology has the potential to further reduce emissions 1.74 to 1.92 tCO_2 in the Indian cement sector.

Latest generation preheater cyclone technology

Energy savings: 0.6–1.5 kWh/t clinker | Sector-wide CO_2 reduction scope: 0.82–1.63 Mt

The kiln feed (i.e. the raw meal) is heated in the preheater and then sent to the precalciner. Modern preheaters perform about 40–60 per cent[30] of the calcination process before the kiln feed (also known as the raw meal) is heated progressively as it passes downward through a vertical tower of cyclone stages (typically five or six cycles or cyclone stages), before entering the precalciner and then into the rotary kiln. The amount of thermal energy that the kiln needs is determined by the efficiency of heat transfer at each cyclone stage. The preheater tower therefore represents a key leverage point for reducing the thermal SEC of the entire process.

Many older plants in India, particularly those operating five-stage preheaters or non-optimally configured six-stage designs, suffer from heat transfer inefficiencies that raise their specific energy consumption. Poor gas-to-solid contact arises when gas velocities or flow paths through the cyclone body are not optimised, causing raw meal particles to spend insufficient time in suspension and exit the cyclone before heat exchange is complete. Uneven distribution of the raw meal across cyclone stages creates situations where some stages are overloaded while others operate below their design throughput, reducing the efficiency of the system.

By utilising the latest technologies in preheating cyclone design and optimising vortex finder geometry, dip tube configurations, and top cyclone design, along with using Computational Fluid Dynamics (CFD) to simulate flow patterns, the efficiency of the system can be significantly improved. The savings from upgrading to the latest cyclone technology can improve performance by 0.6–1.5 KWh per tonne of clinker produced. Based on the capital cost of upgrading an existing five- or six-stage preheater, the cost in India is between Rs 1–2 crore per stage. An entire tower upgrade project is financially viable based on the expected thermal savings. These upgrades can occur in conjunction with routine maintenance schedules to minimise production losses due to the time spent replacing cyclones. Furthermore, improved performance of the existing preheaters will result in more stable kiln operation and consequently reduce the complexity faced by AI-based systems for optimising control. The combined effect of using the latest preheating cyclone technologies together with AI- or computer-based real-time control systems will result in overall improved by up to 0.0003–0.0007 tCO_2/t of cement produced. Factoring in the current adoption rate, this technology has the potential to reduce emissions by 0.12—0.30 $MtCO_2$ in the Indian cement sector.

Kiln radiation recovery through Vapour Absorption Machine (VAM)

Energy savings: 5000 kCal/t clinker | Sector-wide CO_2 reduction scope: 0.88–0.90 Mt

Kiln radiation recovery systems can reclaim thermal energy that would otherwise be lost through radiation and convection from the kiln's exterior to the environment. Kiln radiation is a low-temperature source of thermal energy. By using technologies such as Vapour Absorption Machines (VAM), kiln radiation can be recovered for supplementary operations such as the dehumidification of fossil fuels. Research has shown that kiln radiation recovery systems have an energy savings potential of 5000 Kcal/t of clinker produced. The device can be installed at a cost of less than Rs 50 lakh and has the potential to reduce emissions by approximately

0.0019–0.0020 tCO_2 per tonne of cement produced. Kiln radiation recovery systems are currently adopted by 20–30 per cent of cement plants in India, and the technology has the potential to further reduce emissions by 0.88—0.90 $MtCO_2$ in the Indian cement sector.

Latest-generation clinker coolers

Energy savings: 10,000–20,000 Kcal/t clinker | Sector-wide CO_2 reduction scope: 0.09–0.23 Mt

Immediately after the clinkerisation process, clinkers coming out of the kilns have temperature ranging between 1200°C and 1400°C. In the traditional method, clinker coolers are used to reduce this temperature to around 120°C.[31] This heat is recoverable and can further be directed to a Waste Heat Recovery (WHR) system to achieve maximum energy efficiency, making cooler efficiency a multiplier on the overall heat recovery chain.

The latest-generation clinker coolers are more efficient than their older counterparts at recovering heat from clinkers due to improved control over air distribution over the clinker bed, reduced false air entry, and the ability to more transfer heat efficiently from the clinker to the cooling air stream. The energy-saving benchmark specified for today's advanced clinker coolers is between 10–20 kCal/kg of clinker.[32] This technology can result in additional energy savings of 0.0002–0.0005 tCO_2/t of cement. The capital cost of installing a latest-generation clinker cooler ranges between Rs 18–35 crore, depending on kiln capacity, cooler size and technical design of the plant. At present, about 60–70 per cent plants in India have latest generation clinker coolers installed. Factoring in the current adoption rate, this technology has the potential to reduce 0.09–0.23 $MtCO_2$ in the Indian cement sector.

Advanced equipment for efficient increase in alternative fuel and raw material (AFR) utilisation

Energy savings: 956–1195 Kcal/t cement | Sector-wide CO_2 reduction: 0.13– 0.17 Mt

By substituting fossil fuels (mainly coal and pet coke) with alternative fuels and raw materials (AFR), such as RDF, biomass, industrial and municipal solid wastes, thermal combustion emissions can be reduced. The main challenge to the widespread adoption of AFR is not so much the availability of combustible waste in India, but rather the limitations of traditional kiln systems in handling such fuels that vary in moisture content, calorific value and particle size.

Traditional kilns are designed around the predictable combustion behaviour of pulverised coal or pet coke fuels, which is made up of homogeneous particle size, low moisture and consistent calorific value. When heterogeneous AFR streams are introduced directly into these systems, the variability causes specific and well-documented problems. High-moisture fuels, such as wet RDF absorb heat from the combustion zone to drive off water before combustion can begin, decreasing flame temperatures and creating unburnt zones. Fuels with low or variable calorific value produce inconsistent heat release, making it difficult to maintain stable kiln inlet temperatures. Coarse or irregular particle sizes that are common in shredded municipal waste result in incomplete burnout within the residence time available in the calciner. This leads to unburnt carbon carry-over into the kiln, ring formation from partially combusted material depositing on the kiln lining, and build-up of clinker balls and blockages that reduce throughput and increase specific energy consumption.

Advanced AFR equipment resolves these problems by creating a dedicated pre-treatment and pre-combustion environment before the fuel stream enters the main calciner or kiln. Pre-combustors and hot disc reactors expose the AFR to high temperatures (typically 850 to 1,000°C) and controlled turbulence for a defined residence time, long enough to drive off moisture, initiate and sustain combustion of low-calorific fractions, and reduce large particles through thermal breakdown before they reach the kiln system. Separate-line calciners allow the AFR combustion gases to be fully processed in an isolated stream before being merged with the main gas flow, preventing poorly combusted volatiles from disrupting the thermal profile of the primary calciner. Specialised dosing and feeding systems meter AFR at consistent mass flow rates despite variations in bulk density and particle size distribution, smoothing variability at the source before it propagates into the combustion chamber. Together, these measures ensure that by the time combustion gases from the heterogeneous AFR stream enter the main kiln, they carry a consistent thermal energy content and contain minimal unburnt material as closely as possible for the controlled combustion conditions for which kiln systems were originally designed.

This approach minimises incomplete combustion, ring formation, and deposit build-up, enabling plants to sustain high thermal substitution rates (TSR) that would otherwise be operationally unviable under traditional configurations. The optimised combustion environment delivers a direct thermal efficiency benefit of approximately 4–5 kJ/kg of clinker,[33] equivalent to 956 to 1,195 kCal/t of cement. The capital cost for the equipment is approximately Rs 5 to 10 crore, depending on the configuration and the TSR target. Factoring in the current adoption rate, this technology has the potential to reduce emissions by 0.13 to 0.17 $MtCO_2$ in the Indian cement sector.

Advanced process control based on artificial intelligence (AI) and machine learning (ML)

Energy savings: 1000 Kcal/t clinker | Sector-wide CO_2 reduction: 0.11–0.13 Mt

Modern equipment can achieve significant improvements in energy efficiency compared to traditional methods by using AI and ML to enhance how existing equipment is configured for operation rather than replacing it. The pyro-processing systems utilised in the cement industry have multiple characteristics, including non-linear dynamics, long time delays between inputs and the resulting outputs, and numerous variables that have considerable interactions amongst each other (e.g., the feed rate of fuel, speed of the kiln, feed rate of raw meal, temperature of the calciner, amount of oxygen and amount of drafts). In addition, the use of traditional proportional integral differential (PID) control algorithms to control the operation of these systems is also limited due to multitude of variables and their interactions. AI- and ML-based systems constantly receive information from numerous source sensors installed along the entire kiln system and use the generated information to create and modify predictive models that estimate how the kiln is likely to behave. These predictive models allow the kiln system to foresee process deviations before they occur and make pre-emptive adjustments to the set points of specific equipment to help maintain the operation of the kiln in a state that is closer to optimum thermal efficiency. This is more effective and accurate, compared to the manual system that are reliant on manual controls. The amount of thermal savings that can be realised from AI-based process control is roughly 1,000 kCal/tonne of clinker.[34] Although this amount is not very large on an absolute scale, it is significant since these thermal energy savings are achieved without requiring any type of plant outage, hardware replacement or major capital expenditures. The capital cost of an AI-based process control system varies significantly with plant size and the maturity of the existing instrumentation infrastructure. For smaller kilns in the range of 1,000–2,000 TPD clinker capacity with a reasonably modern distributed control system (DCS) already in place, implementation costs can be in the range of Rs 60 lakh to Rs 1 crore, covering incremental sensor additions and software integration. For medium-to-large integrated plants in the range of 3,000–10,000 TPD, which make up the majority of India's installed clinker capacity, the full implementation cost, including sensor upgrades, data infrastructure, software licensing, and commissioning, is more typically between Rs 2–8 crore.

Across the Indian cement sector as a whole, AI-based process control has been adopted by approximately 30–40 per cent of plants, concentrated primarily among the large integrated producers. The remaining of the sector represents the available scope for further deployment. Closing this gap is estimated to yield an emission reduction of approximately 0.0002—0.0003 tCO_2 per tonne of cement at the plant level, translating to a sector-wide reduction of 0.11–0.13 Mt CO_2 per year at current production volumes.

Electrical energy efficiency technologies

Vertical Roller Mills (VRM) / High-Pressure Grinding Rolls (HPGRs) – Pre-Grinding

Energy savings: 6–10 KWh/t Cement | Sector-wide CO_2 reduction scope: 1.70–2.83 Mt

Grinding comprises around 60 to 70 per cent of a cement plant's total electrical energy usage, making it the biggest lever for improving electrical efficiency. Two technologies have emerged which dominate alternative mechanical methods of grinding, as compared to the conventional ball mill, known as Vertical Roller Mills (VRMs) and High-Pressure Grinding Rolls (HPGRs). They operate on a fundamentally different principle from that of the conventional grinding system. Instead of breaking particulates by impact and attrition, VRMs and HPGRs rely on inter-particle bed compression. This difference in the physical principle of grinding is what gives them their increased efficiency. This is because energy is applied directly at the location of the particulate breakage, rather than using more energy, resulting in waste energy (heat and noise). VRMs combine the processes of grinding, drying, classifying and transporting materials into one machine. VRMs provide accurate control of particle size distribution, along with high moisture tolerance (which is particularly important when considering the shipment of raw materials during monsoon season in India) and require less space for the mill than conventional ball mill systems. Similarly, HPGRs work on a different mechanical principle but achieve similar electrical savings. Two counter-rotating rolls apply very high pressure to a bed of material passing between them. This pressure does not grind the particles to finished size in a single pass. Instead, it fractures them internally, creating micro-cracks throughout the particle structure. When this pre-cracked material enters a ball mill for final grinding, the micro-cracks reduce the mechanical energy the mill needs to break the particles down further, cutting overall electricity consumption relative to ball mill grinding alone. HPGRs can be used either in a pre-grinding process or in a combined circuit alongside a ball mill to produce finished product. Both VRMs and HPGRs have been proven to operate commercially in India, with VRMs becoming standard technology when installing new raw mills and coal mills, while the use of VRMs for producing finished cement continues to increase significantly. These technologies provide electrical energy saving of 6–10 kWh per tonne of cement, as compared to using traditional ball mill circuits. The capital cost associated with installing a VRM or HPGR will typically range from Rs 30-40 crore based on the capacity and configuration of the equipment. At present, about 30-40 per cent plants in India have adopted latest generation clinker coolers. Factoring in the current adoption rate, this technology has the potential to further reduce 0.0037—0.0062 tCO_2/t cement, eliminating 1.70 to 2.83 $MtCO_2$ from the Indian cement sector.

Variable Frequency Drives (VFDs)

Energy savings: 2–5 KWh/t Cement | Sector-wide CO_2 reduction scope: 0.13–0.33 Mt

In cement plants, major applications include fans (in kiln, raw mill, cooler, bag filter etc.), compressors and large pumps. Variable Frequency Drives (VFDs) modulate the speed of electric motors to match process demand, avoiding the inefficiencies of throttling or damper-based control. As this technology has developed, the types of applications with the most potential impact in cement facilities include kiln fans, raw mill fans, preheater exhaust fans, cooler fans and bag filter fans, along with compressors, conveyors and pumps. Due to the principles of fan and pump operation, their optimised and need-based operations result in significant energy savings. Approximately a 50 per cent reduction in power is obtained for a 20 per cent reduction in fan speed, due to the cube law of fluid dynamics.[35] Energy savings in the Indian cement sector due to the deployment of VFDs on key drives throughout a facility are estimated at 2–5 KWh per tonne of cement produced.[36] This significant amount of savings can be attributed to the large percentage of time that fans and motors operate at partial load. The purchase price for a VFD is based on the size of the motor being optimised, with low tension (LT) VFDs costing Rs 10 to 30 lakh for small motors, and high tension (HT) VFDs costing Rs 50–350 lakh for large kiln and mill fans. In spite of this wide range in price between individual VFDs, VFDs as a group frequently have the shortest payback periods of any energy efficiency initiative, typically 18 to 36 months. Since they seldom require plant shutdowns, they can easily be incorporated into existing motor systems, and they start providing savings immediately after installation. In addition to energy savings, VFDs also contribute to improving process control by providing smooth acceleration of motors and, therefore, reducing wear and tear on mechanical components, providing accurate control of gas flow through combustion processes, and providing variable speed drives for artificial intelligence-based process control throughout the facility so that actuators react with higher precision. Closing this gap is estimated to yield an emission reduction of approximately 0.0003–0.007 tCO_2 per tonne of cement, translating to a sector-wide reduction of 0.13–0.33 Mt CO_2 per year at current production volumes.

Table 2: Emerging and Currently Available Energy Efficiency Technologies with Maximum Potential for Emission Reduction in Cement Sector

Technology	Energy saving type	Energy savings (source units)	Capex (In INR)	Industry adoption rate (%)	Estimated further scope of sectoral emission reduction considering industry adoption rate (tCO_2/t cement)
Waste Heat Recovery System (WHRS)	Thermal to electrical	30–35 KWh/t clinker	8–16 Cr/ MW	80–90	0.0030–0.0035
Low-temp WHR	Thermal to electrical	6–7 KWh/t clinker	No data	5–10	0.0038–0.0042
Latest generation preheater cyclone technology	Thermal to electrical	0.6—1.5 KWh/t clinker	1–2 Cr per cycle	30–40	0.0003–0.0007
kiln radiation recovery (VAM)	Thermal	5,000 KCal/t clinker	Below 50 lakh	0–2	0.0019–0.0020
Latest-gen clinker coolers	Thermal	10,000–20,000 KCal/t clinker	18–35 Cr	60–70	0.0002–0.0005
Advanced equipment for increase in AFR utilisation	Thermal (indirect)	1000 Kcal/t	5–10 Cr	20–30	0.0003–0.0004
Advanced process control based on AI and ML	Thermal	1000 KCal/t clinker	60 lakh to 1 Cr	30–40	0.0002–0.0003
VRM and HPGRs	Electrical	6–10 kWh/t cement	30–50 Cr	30–40	0.0037–0.0062
VFD	Electrical	2–5 KWh/t cement	LT: 10–30 lakh HT: 50 lakh–1 Cr	80–90	0.0003–0.0007
Total Emission intensity Reduction Potential					**0.138–0.0185**

Complete deployment of the 9 technologies with available subsequent adoption potential would reduce emission intensity in the Indian cement sector between 0.0138–0.0185 tCO_2/t cement, equivalent 2.19–2.94 per cent of the 0.63 tCO_2/t cement baseline. In absolute terms, this is about 6.26–8.39 MTPA CO_2 reduction from the sectoral total emission of 285.39 MTPA calculated assuming the baseline cement production of 453 MTPA.

6

POLICY CONTEXT: CCTS AND GEI TARGETS FOR THE INDIAN CEMENT SECTOR

The Greenhouse Gas Emission Intensity Target Rules, 2025 (GHG EITI Target Rules), notified by the Ministry of Environment, Forest & Climate Change (MoEFCC), establish facility-level greenhouse gas emission intensity targets for obligated entities across selected industrial sectors, under India's Carbon Credit Trading Scheme (CCTS), which is the fundamental framework for carbon market in India. Targets for the cement sector were officially notified by MoEFCC in October 2025, covering 186 cement manufacturing facilities across six sub-sectors—Portland Pozzolana Cement (PPC), Ordinary Portland Cement (OPC), Composite Cement, Clinkerisation, White Cement and grinding units. Targets are expressed in tCO_2 equivalent per tonne of product, with compliance obligations notified for two years, FY 2025–26 and FY 2026–27. Baseline GEI values for all obligated entities are derived from plant-level emission data for the year 2023–24. Table 3 presents the average GEI reduction targets notified for each cement sub-sector across the two compliance years.

The Portland Pozzolana Cement (PPC) segment, with 75 obligated entities, is the largest sub-sector by number of participants, reflecting its dominant share of the Indian cement market. With an average baseline GEI of 0.5754 tCO_2/t cement, PPC units are assigned a Year 1 average reduction target of 0.0033 tCO_2/t cement

(0.57 per cent), stepping up to 0.0131 tCO_2/t cement (2.27 per cent) in Year 2, bringing the cumulative two-year reduction target to 0.0164 tCO_2/t cement, or 2.84 per cent.

The Ordinary Portland Cement (OPC) sub-sector, with 45 obligated entities and the highest average baseline GEI of 0.8423 tCO_2/t cement, faces the steepest absolute reduction expectations. Year 1 targets average 0.0079 tCO_2/t cement (0.94 per cent), rising to 0.0175 tCO_2/t cement (2.08 per cent) in Year 2, with a cumulative two-year reduction target of 0.0254 tCO_2/t cement, or 3.01 per cent. The relatively higher targets for OPC reflect the regulatory expectation that more carbon-intensive production processes carry proportionally greater decarbonisation potential.

The composite cement sub-sector carries a cumulative two-year reduction of 3.52 per cent (0.0145 tCO_2/t cement), with Year 1 and Year 2 targets averaging 0.98 per cent and 2.54 per cent respectively. Clinkerisation and white cement units, with four and two obligated entities respectively, carry two-year cumulative targets of 2.23 per cent and 3.09 per cent. Grinding units, comprising 55 obligated entities with a low baseline intensity of 0.0310 tCO_2/t cement, face the steepest percentage reduction target over the two-year period at 14.19 per cent, reflecting the comparatively greater room for efficiency improvement at this stage of the production chain.

The sector carries a cumulative baseline intensity of 0.5930 with an emission intensity reduction target of 0.0047 tCO_2/t cement in year 1 (0.80 per cent) and 0.0129 tCO_2/t (2.18 per cent) cement in Year 2. The cumulative target for the sector stands at 0.0177 tCO_2/t cement in two years accounting for a reduction potential of 2.98 per cent. In absolute terms, this stands to 8.02 MTPA of carbon reduction.

Under the CCTS compliance framework, entities that over-achieve their GEI targets earn carbon credit certificates (CCCs), which can be traded on the Indian carbon market. Entities that fall short of their targets are required to purchase CCCs or face regulatory penalties, creating a direct financial incentive for early and aggressive adoption of energy efficiency technologies.

An assessment of the nine energy efficiency technologies indicate that a combined emission intensity reduction potential of approximately 0.0138–0.0185 tCO_2/t cement or 2.19–2.94 per cent reduction from the current industry average of 0.63 (10.15-13.00 MTPA from the overall sector) suggests that energy efficiency improvements alone can help the obligated entities to meet a large part of their CCTS targets across both compliance years. The carbon credit mechanism further amplifies this incentive, particularly for smaller entities that currently operate below industry best practice benchmarks and thus have the most headroom to generate surplus credits.

Table 3: Emission intensity reduction targets for Indian cement industry under CCTS

Sub-sector	Number of obligated entities	Baseline intensity (2023–24) (Average)	CO_2 reduction target for Compliance Year 2025–26 (tCO_2e/t cement) (Average)	CO_2 reduction target for Compliance Year 2025–26 (%) (Average)	Compliance Year 2026–27 Target (tCO_2e/t cement) (Average)	CO_2 reduction target for Compliance Year 2026–27 (%) (Average)	2-Year cumulative GEI reduction target (tCO_2e/t product)	2-Year cumulative reduction (%)
Portland Pozzolana Cement	75	0.5754	0.0033	0.57%	0.0131	2.27%	0.0164	2.84%
Ordinary Portland Cement	45	0.8423	0.0079	0.94%	0.0175	2.08%	0.0254	3.01%
Composite	5	0.4108	0.0040	0.98%	0.0104	2.54%	0.0145	3.52%
Clinkerisation	4	0.8095	0.0050	0.62%	0.0130	1.61%	0.0180	2.23%
White cement	2	0.8891	0.0076	0.85%	0.0199	2.23%	0.0275	3.09%
Grinding	55	0.0310	0.0006	2.08%	0.0038	12.11%	0.0044	14.19%
Cumulative	186	0.5930	0.0047	0.80%	0.0129	2.18%	0.0177	2.98%

7 COST ANALYSIS AND FINANCING OPPORTUNITIES

The primary benefit of energy efficiency investments in cement plants is their future operational cost reduction potential through operational cost savings due to reduced energy consumption in an industry where energy consumption represents 20–30 per cent of total production costs. Therefore, reducing SEC through implementation of energy efficiency technologies provide both strong financial incentives and emission reduction to cement manufacturers who implement them. Many energy efficiency technologies have been commercially available for some time and have a relatively low risk due to their proven record of generating predictable returns, whereas many other technologies and pathways—often called breakthrough technologies—that contribute to decarbonisation (e.g. CCUS , green hydrogen, kiln electrification etc.) are still in the development stage and carry a higher degree of uncertainty currently due to lack of proven commercial models on the ground.

The Capex associated with energy efficiency technologies encompasses a wide range of investment depending on the scale and complication of the technology along with the age of the plant and its ability to adapt.

The Waste Heat Recovery System (WHRS) and advanced grinding systems (VRM/HPGR) are comparatively costly technologies that represent a large portion of the total investment, which reflects in the cost per unit as well as the overall system-wide cost of these technologies. Improvements to thermal efficiency, such as upgrading clinker coolers or modifying preheaters, will account for a large percentage of the investment needed for clinker-producing units; they have broad cross-unit applicability.

Conversely, low-cost interventions, such as VFDs and AI/ML-based process optimisation systems, generally require comparatively smaller investment but provide rapid payback, making them attractive options for immediate deployment. Notwithstanding the large aggregate investment requirement, all of these technologies have the potential to provide economic returns by reducing energy consumption, therefore saving energy costs, which are on a rise in the ongoing energy crisis. They will also enable cement units to meet the targets being set under the CCTS in the next two years and beyond, creating an additional potential economic incentive based on how well the carbon price in India grows.

Table 3: Cost and payback period of major energy efficiency technologies in cement manufacturing industry

Technology	CAPEX range (₹)	Payback period (Months)	Adoption level (Low: 0–30% Medium: 31–60% High:61–90% Very high: Above 90%)
WHRS	8–16 Cr/MW	55–60	High
Low-temp WHR	10–15 lakh	30–36	Low
Latest generation preheater cyclone technology	1–2 Cr per cycle	10–12	Medium
Kiln and preheater radiation recovery (VAM)	Below 50 lakh	24–36	Low
Clinker cooler	18–35 Cr	48–60	High
AFR systems	5–10 Cr	60–72	Low
AI/ML control	0.6–1 Cr	12–24	Medium
VRM/HPGR	30–50 Cr	36–48	Medium
VFD	LT: 10–30 lakh HT: 50 lakh–1 Cr	8–10	Very high

Payback period and economic viability

Effectiveness of energy efficient technologies can be assessed by understanding the payback period, which vary from one intervention to another:

Short payback (One–two years):

Technologies, like latest generation preheater cyclone technology, AI-based optimisation techniques and VFDs, have low capex and low payback time. These technologies provide immediate energy savings with shorter cost recovery time.

Medium payback (Two–four years):

These technologies are comparatively costlier and have longer payback time.

However, the SEC reduction potential is relatively better with better emission reduction potential. This includes Low-temp WHR and Kiln and Preheater Radiation Recovery (VAM).

Long payback (Four years and above):

These technologies have high capex and have relatively longer payback period. However, these provide the highest emission reduction potential and after the investment breakeven point, these provide higher cost savings.

While the payback periods are based on Bureau of Energy Efficiency's estimates,[37] once we account for rising fuel and electricity rates and the cost associated with carbon taxes under legislated frameworks, even higher cost savings and reduced payback period is expected.

Barriers to investment

There are significant economic advantages, however impediments hinder widespread adoption of technological upgrades, particularly within the small to medium size cement producers. This includes:

- High initial capital required for major upgrades
- Limited access to low-cost financing for smaller companies
- Downtime during retrofits causing operational limitation and business loss
- Limited information about availability, vendors, appropriate selection of technologies as per the plant conditions and uncertainty about actual savings
- No major incentive for improving efficiency or reducing emissions currently
- These barriers along with others to adoption will require specific support in the form of financial resources and policy implementation to promote further adoption of the technologies.

Major financing mechanisms for adoption of energy efficient technologies

Assessing financing mechanisms

The financing landscape for industrial energy efficiency in India has evolved considerably over the last decade. While large, well-capitalised cement manufacturers have been early movers in adapting technologies, smaller entities often lack the credit history, collateral, technical data and capacity to access mainstream financing channels. Addressing this financing gap is therefore not merely a financial question, but a policy imperative. The technologies covered in this report are commercially proven and economically viable; what is needed is a structured, non-complicated, multiple-option financing ecosystem that can channel capital efficiently to where the emission reduction potential is greatest. The following sub-sections describe the key financing mechanisms currently available to Indian cement producers, ranging from government schemes and development finance to capital market instruments and equipment leasing.

Internal funding

Cement firms with ample financial resources generally utilise cash flow from operations and their existing asset base (balance sheet financing) as their most straightforward and least expensive means of financing their improvements in energy efficiency. Companies with a positive operating cash flow and a sound credit rating have been able to fund the required capital for technology improvements, including the installation of waste heat recovery systems (WHRSs), replacement of vertical roller mills (VRMs), and the implementation of AI-based process control systems entirely through retained earnings. However, funding through one's own income is not always possible for all, especially smaller businesses, which usually have a very small profit margin, leaving them few retained earnings to make discretionary capital investments. Additionally, although energy efficiency improvement (investments) has the potential to produce high returns on investment, as compared to investments made in increasing capacity, energy efficiency improvement investments often compete with capacity expansion projects that are considered to be of higher strategic importance internally. Without the existence of a strong carbon price signal or regulatory mandate, internal capital allocation committees may deprioritise energy efficiency improvements in favour of growth-related capital investments. This creates a structural barrier (an implicit barrier) to making energy efficiency improvements, at times, even if company has funds available to invest in making energy efficiency improvements. Therefore, a strong policy signalling in the country is essential and it should be such that can influence internal company and board room decisions on investment.

Government and regulatory schemes

There have been many changes in the options available to finance industrial energy efficiency in India over the last ten years. The PAT (Perform, Achieve, Trade) scheme created India's first market-based mechanism for monetising energy savings through ESCerts (Energy Saving Certificates), providing financial justification for investing in energy efficiency beyond just lower costs. As CCTS comes into enforcement, there will be an additional financial benefit available to facilities (as the carbon price matures over time) that outperform their emission intensity target with the introduction of a carbon pricing signal which has the potential to provide direct revenue to these facilities. Although, many manufacturing units, especially the smaller ones, may face financial burden of rising compliances in the country.

A multi-option financing ecosystem in place will increase the possibility of comparatively low cost and faster capital mobilisation for emission reduction potential. Various options of financing can include government financing, development finance, loans, capital market, equipment leasing and other upcoming innovative financing mechanisms. Addressing the lack of financing will not only require financial mechanisms, but also policy frameworks that back them effectively.

Development finance institutions (DFIs)

The Indian Renewable Energy Development Agency (IREDA) and the Small Industries Development Bank of India (SIDBI) are the primary development finance institutions (DFIs) in India providing finance to promote energy efficiency investments in industry. IREDA provides term loans, refinancing lines of credit and project loans for long tenures. As an example, SIDBI's Green Finance Scheme provides loans of up to Rs 20 crore at interest rates ranging from 7.6 to 9.4per cent,[38] which is accessible for small and medium-sized cement manufacturers. For larger projects, SIDBI maintains the Partial Risk Sharing Facility (PRSF), which offers credit guarantees equal to 40 to 75 per cent[39] of the loan amount (up to Rs 15 crore per project) to financial institutions, thus reducing the lenders' perceived risk of lending for energy efficiency projects. With the establishment of Energy Efficiency Financing Platform (EEFP) by BEE, the gap between borrowers and lenders is being closed by bringing the cement producers and financial institutions together onto a common platform. Under this initiative, BEE has entered into MoUs with IREDA, SIDBI, YES Bank and Central Bank of India.

Even with an established institutional framework, DFI funding for energy efficiency projects in the industrial sector is still not substantial. A major barrier to unlocking the full potential of DFI financing for energy efficiency improvements is the need for investment-grade energy audits and detailed supporting documents, which many of the smaller cement plants do not have the capacity to develop. Further complicating the issues related to accessing DFI financing for energy efficiency improvements are the lengthy loan appraisal processes at DFIs. Apart from that, the SME finance guarantee limit of Rs 15 crore for the PRSF programme is not sufficient for capital intensive upgrade projects (WHRS or VRM), which acts as a limitation in terms of useful financing sources for small scale projects.

ESCO model

The Energy Service Company (ESCO) model is particularly relevant for small and mid-sized cement producers that lack upfront capital for equipment upgrades. Under this model, the ESCO finances, installs, and operates the energy-efficient equipment, and the cement plant repays costs from the resulting energy savings—requiring little to no initial investment. The PRSF facility explicitly supports ESCO-based projects using Energy Service Performance Contracts (ESPCs), addressing the risk perception that financial institutions typically associate with such arrangements.

Although the ESCO market in India has attractive prospects, it has a still-underdeveloped status and faces many structural constraints. Supply-side constraints arise from only a few ESCOs having the technical capacity to handle the complexity of cement plant systems. Due to inadequate baseline data and metering infrastructure at older cement plants, there are often limitations to measurement and verification of energy savings.[40]

Bank and NBFC financing

Interest rates for equipment loans from commercial banks typically range between 8 to 12 per cent with loan repayment option between three to seven years. Some banks and NBFCs also offer lease-to-own schemes, which combine the flexibility of leasing with a pathway to eventual ownership, allowing users to purchase the asset at the end of the lease term. While bank supported financing is more financially suitable, the lending practices of many commercial banks inhibit new establishments because the majority of the lenders evaluate based on collateral asset and balance sheet strength over projected energy savings and credit revenues. Small cement producers face significant challenges when attempting to finance energy-efficient upgrades to an existing facility or for a new independent project, as they are largely unable to secure sufficient asset collateral from their lenders. Additionally, loan officials associated with many commercial banks often lack the technical understanding of energy efficiency projects and how to assess the risk and benefits accurately. This leads to conservative underwriting and loan rejections.

Green bonds and sustainability-linked loans

Large cement manufacturers have access to debt instruments, such as green bonds and sustainability linked loans (SLLs) from the capital markets. The interest rate on SLLs is linked to sustainability key performance indicators (KPIs), such as the proportion of energy sourced from renewable sources and targets for reducing emissions, thereby providing a financial incentive to reduce emissions. Through the Securities and Exchange Board of India's (SEBI) ESG Bond Framework, cement companies can issue green bonds for investments related to energy efficiency, which can be held as a separate fund or account. However, certain challenges in accessing green bonds and SLLs exist for many cement companies. Green bonds and SLLs are typically only available to large, publicly traded cement companies that have a well-established ESG reporting framework and a well-known credit rating. The cost of issuance, which typically includes the services of third-party green certification, the legal services for documentation and continuous impact assessment and reporting can be prohibitively expensive for small to mid-sized cement producers. Additionally, as a result of increased scrutiny by investors and rating agencies on greenwashing, the ability to achieve and genuinely showcase significant emission reduction is dependent upon the effectiveness of the MRV system of each company.

Multilateral and bilateral development finance

Large scale capital expenditure projects can be funded or supported by multilateral financing institutional agencies such as the World Bank, Asian Development Bank (ADB), and International Finance Corporation (IFC) through the provision of concessional finance or credit guarantees. The Clean Technology Fund (CTF) of the World Bank provides support to the PRSF programme through the Small Industries Development Bank of India Limited (SIDBI). Additionally, KfW (Germany) and JICA (Japan) bilaterally provide concessional financing lines for clean technology investments to the industrial sectors in India. Vulnerabilities of the multilateral financing provisions, although concessional in nature, are due to their high degree of procedural complexity. In addition to that, compliance with various environmental and social safeguard frameworks used by the multilateral institutions require additional preparation costs and documentation.

Equipment leasing

Equipment leasing is a financing arrangement whereby a company (the lessee) pays periodic fees to use an asset owned by another party (the lessor), rather than purchasing it outright. Leases are typically structured to also include maintenance and servicing of the equipment, which reduces the operational risk for the lessee. The use of leasing as a means to achieve a financing is particularly advantageous to companies that are willing to purchase a new technology but want to test before committing any significant amount of capital. In addition to financing the equipment that is being leased, maintenance and servicing provisions are typically included in a lease, thereby decreasing the risk of losses to the cement plant during operational downtime. However, the leasing market for heavy industrial machinery in India is much less developed than the leasing for logistics (eg., trucking/transportation) or construction equipment. Lessors are also generally hesitant to provide financing of highly specialised equipment that can be used at a cement plant, as there is no readily available secondary market for the equipment.

8 CONCLUSION

The cement industry in India is at a critical point. The total installed capacity is expected to expand rapidly over the coming decade. Even though the sector has achieved improvements in energy efficiency, an increase of this magnitude in production will have major consequences for India's emissions trajectory and its national climate change commitments. There is an array of energy-efficient technologies available for the cement sector. This report attempts to identify the most impactful and commercially available options that can be leveraged to achieve significant emission reductions through energy efficiency in the near future. The study shows that adoption of these technologies across the sector could reduce emissions by 0.0138–0.0185 tCO_2/t cement or 2.19–2.94 per cent. This would translate into a reduction of 6.26–8.39 MTPA in the current total emission intensity from the sector.

It is important to note that the potential for energy efficiency will likely differ from plant to plant depending on its current condition and capacity. There is a need for policy interventions to provide easier access to finance, information and technological understanding, especially for smaller and older plants. With the commencement of the CCTS, energy efficiency will play a crucial role in enabling the sector to achieve its targets for the upcoming two years and beyond.

The sector faces a cumulative CCTS compliance target of 0.0177 tCO_2/t cement (2.98 per cent reduction), or 8.02 MTPA of absolute emissions reduction over 2025–26 and 2026–27. The energy efficiency technologies evaluated in this report can deliver majority of this required target. This shows that energy efficiency measures alone are sufficient to enable cement facilities to meet their greenhouse gas emission obligations in the near term.

Achieving deeper decarbonisation beyond this will require clear strategies, targets and investments in pathways such as increasing TSR in the plants, reducing the clinker factor, use of upcoming fuels like green hydrogen, electrification of kilns, along with CCUS for residual emissions.

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India is world's second-largest cement producer. With capacity set to expand by 160–170 million tonnes by 2028, the sector's emissions trajectory carries major consequences for the country's climate commitments. This report examines energy efficiency as the most immediate and cost-effective lever for decarbonising cement manufacturing in India. This report profiles nine key technologies and finds that their remaining adoption could reduce sectoral emissions by 0.0138–0.0185 tCO_2/t cement from a baseline of 0.63 tCO_2/t. These measures could also help the cement sector meet its near-term targets under the Carbon Credit Trading Scheme.

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