Environmental and Resource Assessment for Uptake of LC^3 in India's Cement Mix

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ABBREVIATIONS

Abbreviation	*Full Form*
BAU	Business As Usual
CO_2	Carbon dioxide
CIDEM	Centro de Investigación y Desarrollo de Estructuras y Materiales
CAGR	Compound Annual Growth Rate
°C	Degree Celsius
EPFL	École Polytechnique Fédérale de Lausanne
GWh	Giga Watt Hour
GHG	Greenhouse Gas
IBM	Indian Bureau of Mines
IIT	Indian Institute of Technology
LC^3	Limestone Calcined Clay Cement
LCP	Low Carbon Pathway
MW	Mega Watt
MPa	Megapascal
OPC	Ordinary Portland Cement
PAT	Perform Achieve and Trade
PPC	Portland Pozzolana Cement
PSC	Portland Slag Cement
SDC	Swiss Agency for Development and Cooperation
TARA	Technology and Action for Rural Advancement
USD	United States Dollar
WHR	Waste Heat Recovery
WBCSD	World Business Council for Sustainable Development

EXECUTIVE SUMMARY

The Indian cement industry is a vital part of its economy, providing direct and indirect employment to more than a million people in the country. In 2018, the country produced 298 million tonnes of cement (equating to a 7% share of the global mix) and has installed production capacity of 502 million tonnes per annum. Its cement production is expected to undergo a phase of rapid expansion between 2020 to 2050, following the projected growth in the country's construction sector. The country's cement production is estimated to grow to nearly 1,042 million tonnes by 2047, close to 300% increase from current production amount. This inevitable expansion of the cement industry will lead to an increase in the Carbon Dioxide (CO_2) emissions to unsustainable levels, reaching 674 million tonnes by 2047 (25% of the total GHG emissions of the country at present). Apart from the above environmental implications, Business As Usual (BAU) growth will result in serious mineral resource issues and divergence of compliance with national and international regulations. The current availability of cement-grade limestone is 14,000 million tonnes. It is projected that, by 2047, BAU scenario will require sourcing of 9,400 million tonnes of additional limestone resources which, at present, are not commercially exploited and would require mining in eco-sensitive zones and inaccessible areas. Thus, it is evident that the pursuit of the current pattern of cement production will be unsustainable from both the environment and resource perspective.

Limestone Calcined Clay Cement (LC^3) is a blend of clinker with 30% calcined clay and 15% non-cement grade limestone and presents a potentially viable solution in addressing the looming environmental and resource crunch. LC^3 utilises medium grade Kaolinitic clays and limestone that are abundantly available in the country, thereby significantly reducing the clinker factor in cement production. Moreover, it contributes to 30% reduction in CO_2 emissions and is energy and cost effective. Lastly, LC^3 can be produced in a process compatible with OPC and PPC by integrating and blending with existing manufacturing equipment, leading to only marginally increased investments for installation of calcining equipment. The introduction of LC^3 in India's cement mix has the potential to significantly enhance the environmental and resource performance in the country's cement sector. The scenario building with LC^3 becoming a significant constituent of the cement mix is presented in the Low Carbon Pathways (LCPs) roadmap.

In order to ascertain the net-positive effects due to introduction of LC^3, a comparative analysis of the environmental and resource performance has been carried out between diverse cement production scenarios, termed as Business As Usual (BAU) and Low-Carbon Pathway (LCP) scenarios; involving production of LC^3. The period of performing the analysis is twenty-five years, i.e. from 2022 to 2047.

The BAU scenario is essentially an extension of the prevailing cement scenario in the country till 2047. The trajectory of overall cement production shall follow the projections created by NITI Aayog which envisage production of around 1,042 million tonnes of cement by the year 2047. Characterised as a base scenario, BAU involves continued production of the three dominant cement varieties in India (namely PPC, OPC and PSC) between the period 2022 to 2047. It is assumed that the Indian cement production mix will be identical to the current scenario and remain unchanged throughout the assessment period (2022-2047). Thus, the percentage contribution of PPC, OPC and PSC to total cement production will stay at 67%, 25% and 8% respectively. This translates into a cumulative production of 12,282 million tonnes of PPC, requiring nearly 3,070 million tonnes of fly ash over the entire assessment period. Although the share of coal in India's electricity mix will gradually fall, it will continue to play a dominant role by 2047. This will ensure sufficient generation of fly ash in the country thereby fully catering to the expected demand for PPC production. Moreover, in this scenario contribution from other cement varieties (white cement, rapid hardening cement etc.), which remains minimal at present, will not be considered. Based on the above assumptions, this scenario is considered to be unsustainable. Keeping along the pathway envisaged under this scenario will result in huge increase in country wide GHG emissions, overexploitation of critical natural resources (like limestone) and degradation of large swathes of protected areas. Low Carbon Pathway (LCP) scenarios are proposed as feasible alternatives to the BAU scenario, having the same duration, i.e. 2022-2047. The quantum of overall cement production shall follow the BAU. The key differentiator between the BAU and LCP scenarios is the introduction of LC^3 along with the three main cement varieties (PPC, OPC and PSC). The 'overarching' LCP scenario has been further divided into three distinct sub-scenarios namely, LCP-1, LCP-2 and LCP-3. All three LCP sub-scenarios consider uptake of LC^3 production in India's overall cement mix starting from 2022 (the zero year), to varying degrees to reach different levels of saturation. The production of LC^3 is gradually scaled up to obtain a certain percentage share by the year 2035, which is projected to remain constant till 2047. The extent to which LC^3 penetrates the cement mix by 2035 is different for each sub-scenario, increasing from LCP-1 to LCP-3. The penetration rate of LC^3 in LCP-1, LCP-2 and LCP-3 is 15%, 33% and 50% respectively. This corresponds to a cumulative production of 2,384, 5,240 and 7,937 million tonnes of LC^3 in LCP-1, LCP-2 and LCP-3.

Such levels of production will accordingly require nearly 715, 1,572 and 2,381 million tonnes of China Clay over the entire assessment period. Irrespective of the scenario, based on latest data from Indian Bureau of Mines (IBM), it was determined that India has sufficient reserves of China Clay to fully cater to the expected demand for LC^3 production. In the zero year, the starting percentage shares of PPC, OPC and PSC will be 67%, 25% and 8% respectively, same as BAU scenario. However, the percentage shares for PPC and OPC will not stay constant, which is a deviation from the BAU scenario. This is due to the introduction of LC^3 in the cement mix. For PPC, the percentage share will decrease in LCP-2 and LCP-3 only, while for OPC it will decrease in all the three sub-scenarios to 10% by 2035 and stay constant thereafter till 2047. In line with BAU, PSC will have a share of 8% that will remain constant throughout the period. Moreover, the starting percentage share of LC^3 in the overall cement mix in India will be 1%, which will be based on the type of sub-scenario (i.e. LCP-1, LCP-2 or LCP-3). It should be noted that LC^3 production will only start from 2023 (first year), although the period of assessment starts from the zero year.

Summaries of the essential features of each LCP sub-scenario have been provided below:

Low Carbon Pathway-1 (LCP-1) Scenario - Key Highlights

- LC^3 consumes the market share of OPC only
- Total percentage share of LC^3 in overall cement mix by 2035 will be 15% and stay constant thereafter till 2047
- PPC and PSC percentage shares to be at 67% and 8% respectively, OPC to reduce to 10% by 2035 and stay constant till 2047

Low Carbon Pathway-2 (LCP-2) Scenario - Key Highlights

- LC^3 consumes the market share of both OPC and PPC
- Total percentage of LC^3 in overall cement mix by 2035 will be 33% and stay constant thereafter till 2047
- PSC percentage share to be 8%, OPC to reduce to 10% by 2035 and stay constant thereafter; balance shall be PPC

Low Carbon Pathway-3 (LCP-3) Scenario - Key Highlights

- LC^3 consumes the market share of both OPC and PPC
- Total percentage of LC^3 in overall cement mix by 2035 will be 50% and stay constant thereafter till 2047
- PSC percentage share to be 8%, OPC to reduce to 10% by 2035 and stay constant thereafter; balance shall be PPC

This study has concluded that scenarios with introduction and growing proportion of LC^3 have a better environmental performance and improved resource utilisation compared to BAU. Each LCP sub-scenario leads to a lowering of clinker factor and corresponding CO_2 emissions. The IBM data shows that the non-ceramic grade China clay is widely available in India, overlapping with existing cement plants and captive mines. Moreover, in terms of resource performance, all LCPs generate a fair amount of limestone savings, support utilisation of non-cement grade limestone and non-ceramic grade China Clay.

In this study, LCP-3 scenario represents the most aggressive pathway and involves highest penetration of LC^3 in the Indian cement mix. Thus, implementing LCP-3 scenario would provide the highest environmental and resource benefits compared to BAU. Between 2022 to 2047, the cumulative CO_2 savings that would result from this scenario are 1,221 million tonnes, which is 45% of India's current GHG emissions. It is observed that the terminal value of the clinker factor for LCP-3 scenario will approach 0.59. This matches the target of 0.58 set up in the low carbon roadmap envisaged for sustainable production in India by WBCSD. Alternatively, WBCSD has considered five important levers (which does not include LC^3) that will help attain the targeted clinker factor value namely AFR, thermal and electrical efficiency, clinker substitution, WHR, and newer technologies. Thus, adoption and integration of LC^3 in the overall cement mix has potential to attain the same long-term sustainability performance which will be delivered by all of the 'low carbon' levers combined. In terms of resource performance, LCP-3 scenario would also lead to a cumulative saving of 3,274 million tonnes of cement-grade limestone and nearly 1,191 million tonnes of non-cement grade limestone. This cuts down the additional limestone resources to be, hitherto, prospected by 35% compared to BAU scenario. Lastly, it promotes utilisation of about 2,381 million tonnes of China Clay; which is abundantly available in the country.

It is estimated that continuation of the BAU scenario will lead to severe effects on the environment and natural resources by the year 2038. It is projected that in the ensuing decade till 2047, BAU scenario will require nearly 9,400 million tonnes of additional limestone resources which, at present, are not commercially accessible and would require mining in eco-sensitive zones. In the aggressive LCP-3 scenario, the introduction of LC^3 extends the utilisation of available limestone resources by three years. It further curtails the additional mined limestone resources to 6,100 million tonnes. This impending reality necessitates an early action which will involve an accelerated uptake of LC^3 in India's cement mix in order to ensure sustainable growth in the country.

Introduction

CHAPTER 1

Cement is defined as a hydraulic material made of finely ground nonmetallic, inorganic material which when mixed with water forms a paste that sets and hardens by hydration which retains its strength and stability even under water. It is a key constituent in buildings and civil engineering constructions and its usage is an important indicator of socio-economic progress. Since its development in early 1800s, cement has been a mainstay of construction activities globally, ranging from a small residential dwelling to a massive public infrastructure projects. The cement manufacturing process can be effectively broken down into the following broad stages: extraction and sourcing of raw materials like limestone, gypsum, fly ash etc. to the cement plant, raw materials processing and clinkerisation, grinding of clinker and blending with other additives to form powdered cement, packing and transportation of the final product. There are different varieties of cement based on different compositions according to specific end uses, like, Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC), White Cement among others.

Environmental and Resource Challenges in India

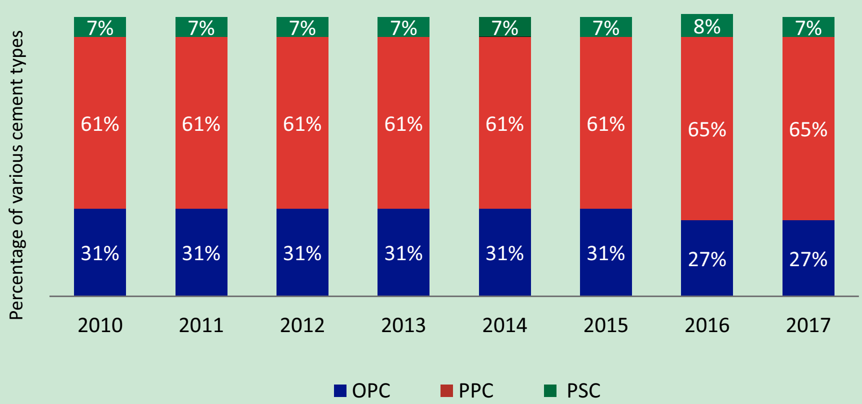
Cement production is one of the most resource and energy intensive processes causing significant impact on the environment (through generation of CO_2 emissions and solid and liquid waste) and natural resource base (used as both raw materials and fuels).

Environmental Challenges

Clinker Factor

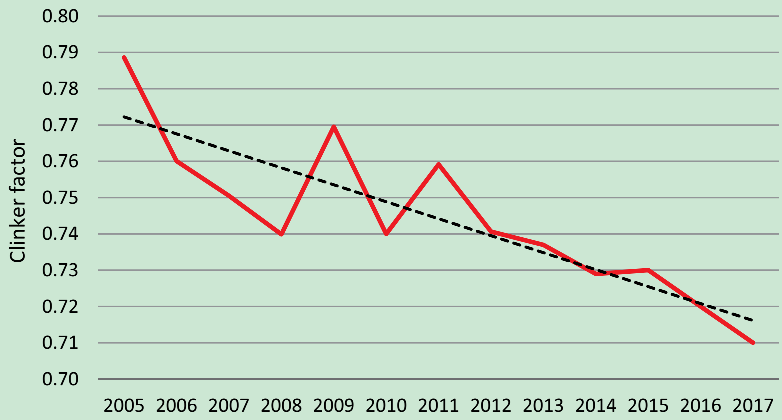
In India, in the past decade, the share of blended cement in total cement production has increased from 68% in 2010 to around 72% in 2017 [1]. This escalation can be attributed to a variety of reasons viz. availability of fly ash and ground blast furnace slag from respective sources, growing market acceptance, increasing focus towards adopting sustainable measures and usage of state-of-the-art techniques and technology. Figure 1 provides a trend in overall cement mix in India between 2010-2017.

Figure 1: Current trend in overall cement mix in India



The clinker factor in India has reduced by more than 10%, steadily falling from 0.79 in 2005 to 0.71 in 2017 [2]. Figure 2 provides a trend in clinker factor in India between 2005-2017.

Figure 2: Current trend in clinker factor in India



However, the current clinker factor in the country is still greater than the world's average value of 0.66 and China's value of 0.60 [3]. A high clinker factor represents more consumption of limestone and increased generation of GHG emissions during the production process. Thus, it is our environmental imperative to further reduce the clinker factor in India.

CO_2 emissions

The Indian cement industry contributes a significant amount to the total anthropogenic CO_2 emissions, comprising a 7 to 8% share of the total annual CO_2 emissions (mirroring global scenario) released in the country [4]. Since the turn of the millennium, the CO_2 emissions from the cement industry have increased by a CAGR of 4.9%, going from 45.97 million tonnes CO_2e in the year 2000 to 108.90 million tonnes CO_2e in 2017 [2]. Figure 3 provides a trend in the CO_2 emissions from the cement industry in India between 2000 and 2017.

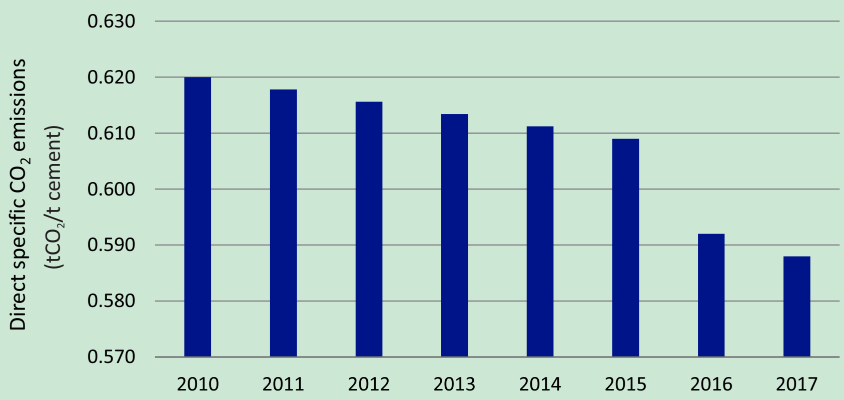
Figure 3: Current trend in CO_2 emissions from cement industry in India

The magnitude of projected demand for building and infrastructure in the country will result in cement industry expanding threefold till 2050, resulting in a proportionate increase in the sector's carbon dioxide (CO_2) emissions. This is a cause for concern as release of such large quantities of CO_2 into the atmosphere will exacerbate the extent of global warming and intensify the effects related to climate change. Further, the projected rise in CO_2 would be incompatible with the climate commitments made at COP 21 and result in our failure to meet the 2°C average global temperature increase limit.

Although the direct and indirect specific CO_2 emissions related to cement production in India have dropped by a third since 1996, the total absolute CO_2 emissions have been steadily increasing (as indicated in Figure 3).

Looking at recent trends, the direct specific CO_2 emissions due to cement production have decreased by 5.2%, going from in 0.620 tCO_2/t cement in 2010 to 0.588 tCO_2/t cement in 2017 [2]. Figure 4 provides a trend in direct specific CO_2 emissions from 2010 to 2017.

Figure 4: Current trend in direct specific CO_2 emissions in India



An emerging cause of concern is that a dedicated shift towards a green and circular economy could disrupt future production and availability of key Secondary Cementitious Materials (viz. fly ash and slag) in some areas of the country. This can result in levelling off in their supply leading to a failure in meeting the burgeoning cement demand. This is likely to impede the future growth in production of the current varieties of blended cements (viz. PPC and PSC). Absence of suitable alternatives may compel cement companies to produce more Ordinary Portland cement, thereby increasing the average clinker factor domestically and globally. The consequences of this will be increased consumption of limestone subsequently causing a surge in global CO_2 emissions. This potential risk presents an opportunity to fast track development and introduction of a low clinker content cement in the Indian mix of cements.

Resource Challenges

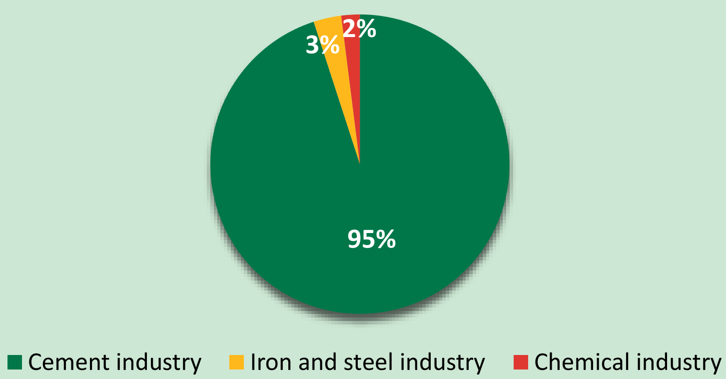
Cement production is primarily dependent upon assured availability of limestone, fly ash and slag as a raw materials and pet-coke and coal as fuel sources to power the production process. Presently, in India, the cement sector accounts for consumption of nearly 288 million tonnes of limestone [5], 19 million tonnes of pet-coke (75% of total demand) [6] and 7.7 million tonnes of raw coal [7]. Additionally, it is also responsible for around 24,000 GWh of electricity usage (equivalent to consuming 4 million tonnes of coal), which is 5% of total industrial use [7]. Driven by a burgeoning demand from construction and infrastructure sectors, the domestic cement industry is projected to expand by 5 to 7% annually till 2030 and beyond [8]. The prospects of future growth brings in a host of challenges as well, chief amongst them is ensuring continued supply of material resources to meet future demand. The projected demand pattern will exert enormous stress on the both primary and secondary material resources (used as raw materials and fuels) and identified above.

The future availability of cement-grade limestone has been recognised as one of the primary resource challenges faced by the Indian cement industry, which is further elaborated in the section below.

Limestone Consumption

Limestone is the main raw material used for cement production and typically constitutes the largest share (ranging from 65 to 95%) in the cement recipe. As an established thumb rule, each tonne of cement production requires nearly 1.4 to 1.5 tonnes of raw limestone [9]. The cement industry accounts for more than 90% of the overall limestone consumption in the country. The industry-wise break up of limestone usage has been provided in Figure 5.

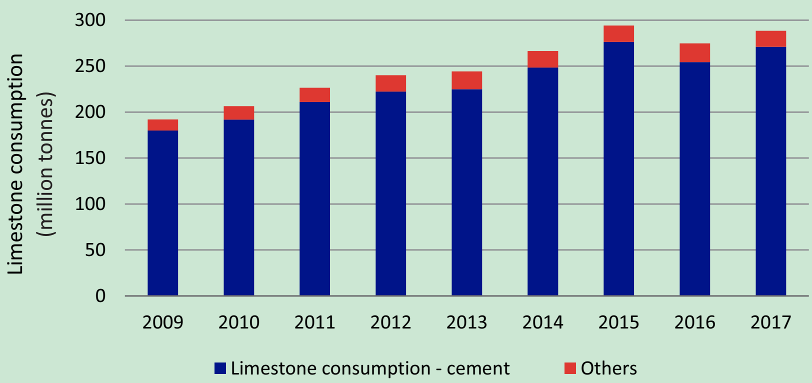
Figure 5: Modes of limestone utilisation in India



The widespread availability of cement grade limestone and sustained construction activity are the foremost reasons for the rapid and sustained expansion in capacity of the Indian cement industry. As per the Indian Bureau of Mines (IBM) data released in 2018, the total resources of limestone in the country were estimated to be about 203,224 million tonnes [5]. Out of that, the availability of proven limestone reserves was estimated to be around 9,438.94 million tonnes [5]. Around 90% (8,495.04 million tonnes) of the proven limestone reserves found in India are cement grade (i.e. having at least 40% Calcium Oxide content) [5]. Remaining 10% (943.90 million tonnes) are categorised as Blast Furnace, Chemical, Paper, Unclassified and Other grades. Further, the geographical availability of limestone is fairly restricted within the country, with only a few states viz. Karnataka, Andhra Pradesh, Rajasthan, Gujarat and Meghalaya accounting for nearly 70% of the total existing resources [5]. The annual average limestone consumption from 2011-2017 was reported to be about 252 million tonnes [5].

Figure 6 provides the trend in consumption of limestone in the period between 2009-2017.

Figure 6: Current trend in limestone consumption in India



Based on projected cement demand, the country is likely to run out of proven limestone reserves latest by 2040. The imminent exhaustion of limestone reserves would either lead to further extraction of remaining resources in eco-sensitive zones or import of limestone from other countries; both being opposed to the basic tenets of sustainability. Further, both these factors will be detrimental to the Indian cement industry which is heavily reliant on easy availability and cheap supply of domestic limestone.

Past sustainability performance

The Indian cement industry is regarded as the most technologically advanced, energy-efficient, cost-effective and one of the least carbon-intensive in the world. This has been made possible through industry's successful integration of sustainability practices across the entire value chain. Specifically, in the past decade, the cement manufacturers through introduction of various cutting-edge technologies, operational innovations, climate-resilient resource optimisation measures and conformance with stringent standards have created environmental and economic benefits. The main achievements of the cement industry have been highlighted in the forthcoming section.

A snapshot of the sustainability performance has been provided in Table 1 (Source: WBCSD).

Table 1: Snapshot of Indian cement industry's sustainability performance	
Percentage share of blended cements	72%
Utilisation rate of Alternate Fuels	3%
Total installed WHRS capacity	344 MW
CO_2 emissions intensity	670 $kgCO_2$/t cement

In the past decade, the CO_2 emissions intensity due to cement production has reduced by 6.8%, falling from 710 $kgCO_2$/t cement in 2010 to 670 $kgCO_2$/t cement in 2017 [1]. During the same period, the share of blended cement in total cement production in India has increased from 68% in 2010 to around 72% in 2017 [1]. The Waste Heat Recovery System (WHRS) capacity in India has almost doubled (increased by 212%) since 2010, attaining a total installed capacity of 344 MW in 2017 [1]. This period has also seen consistent and ever-growing utilisation of alternative fuels (for proving thermal energy), with the usage rates increasing five-fold going from 0.6% in 2010 to around 3% in 2017 [1]. Overall, the industry consumed more than 1.2 million tonnes of alternative fuels in 2017, with biomass contributing to around 24% of the total usage [1]. This has resulted in the cement industry easily meeting its electrical and thermal energy reduction targets set under the PAT scheme (cycle 1).

Although the above-mentioned achievements have resulted in significant environmental and economic benefits, there are possibilities of further improvement which can only be brought in by advancement in technologies, techniques and other measures related to the cement production process.

Outlook

India's cement production is projected to grow at a rapid pace between 2020 to 2050, following the projected growth in GDP. This growth is seen because of increased demand by the development and construction sector, especially for housing and infrastructure needs. Specifically, the major growth drivers for the Indian cement industry in the near future have been highlighted below:

I. **Government initiatives and programs:** Government's increased emphasis in providing affordable housing through higher investments and ensuring better credit facilities leading to the launch of Housing for All program and subsequently the Smart Cities Mission; which are expected to provide a huge fillip to market demand.

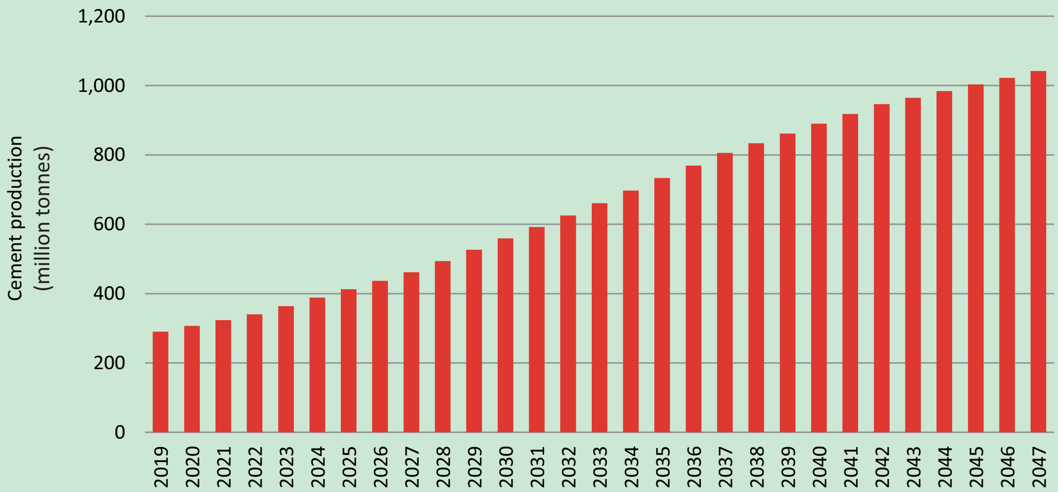
ii. **Infrastructure development:** Increase in infrastructure investment particularly for development of dedicated freight corridors and new/upgraded airports and ports will likely drive building and construction activities.

iii. **Flourishing Real estate sector:** The flourishing real estate market, projected to grow at a CAGR of 11.6% over 2011-20, is expected to reach USD $180 billion by 2020 [10].

iv. **Other major drivers:** Other major drivers include the rising middle-class and their purchasing power, increasing urbanisation through both population expansion and migration from rural areas and the rise in the number of households.

As per the NITI Aayog's forecast, India's cement production is expected to grow to 1,042 million tonnes by 2047, close to 300% increase from current production amount [11]. Figure 7 provides a long-term forecast for cement production in India from 2019-2047.

Figure 7: Forecast trend in cement production in India



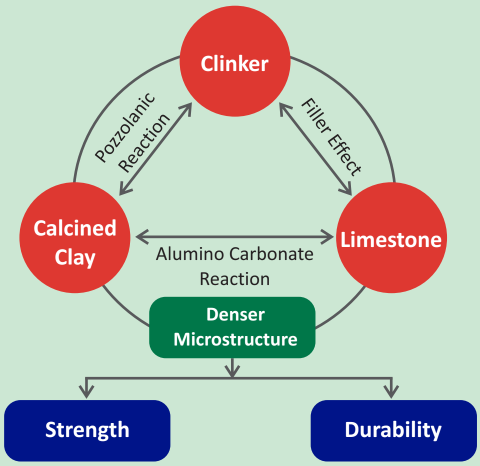
LC^3: An Opportunity

CHAPTER 2

Limestone Calcined Clay Cement (LC^3) has emerged as one of the potentially viable solutions in addressing the looming environmental and resource crisis. It has been developed through sustained and collaborative efforts of multiple organisations namely EPFL (École Polytechnique Fédérale de Lausanne) Switzerland, Society for Technology and Action for Rural Advancement (TARA) India, Centro de Investigación y Desarrollo de Estructuras y Materiales (CIDEM) Cuba, Indian Institute of Technology (IIT) Delhi and IIT Madras, with financial support from the Swiss Agency for Development and Cooperation (SDC).

LC^3 is an innovative cement variety that is composed of a blend of Portland cement clinker, low grade limestone and calcined clay. The LC^3 blend works on the synergy between clinker, calcined clay and limestone phases. Calcined clay reacts with hydration products of clinker and limestone reacts with calcined clay, giving phases that make the microstructure denser. Calcined clays have been long used as pozzolanic materials in cements and limestone is an established semi-reactive filler in cements. The added synergy from the reaction of calcined clays with limestone producing carboaluminate phases improves the strength and durability of the LC^3 cement. Figure 8 provides a synergy diagram for formation of LC^3.

Figure 8: Synergy diagram for formation of LC^3



Constituents of LC^3

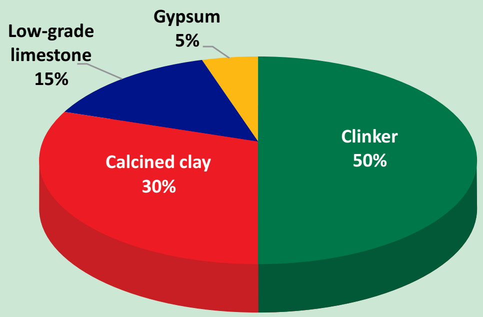
As mentioned, LC^3 is a type of blended cement composed of four basic ingredients namely clinker, calcined clay, non-cement grade limestone and gypsum. Typical LC^3 cements contain 40 to 65% clinker by weight, 30 to 38% calcined clay, 15 to 20% crushed non-cement grade limestone and 3 to 7% gypsum. Figure 9 provides a break-up of the typical composition of LC^3.

Normal Portland clinker, used in existing cement compositions, can be used to produce LC^3. Clinkers and OPCs from throughout the country have been successfully tested to produce LC^3 blends. Kaolinitic clay (china clay) containing 40% to 70% kaolinite content are ideally suited to produce LC^3. Kaolinitic clays and low-grade limestone are widely available as mine residues with limited use in ceramic industries. LC^3 has the potential to utilise these abundant resources and thereby significantly reduce the clinker factor in cement production.

The clays are calcined at 750°C to 850°C to make them reactive, markedly lower than clinkerisation temperature of 1,400°C to 1,500°C. This difference in temperature means that the calcination process requires less than half the energy compared to clinkerisation process.

LC^3 can be produced in a process compatible with OPC and PPC by integrating and blending with existing manufacturing equipment. The only marginally increased investments will be for installation of calcining equipment.

Figure 9: Typical composition of LC^3



The pilot formulations of LC^3 (containing a blend of just 50% clinker with calcined clay and low-grade limestone) derived under laboratory conditions by Indian partners have been successfully implemented in industrial trials conducted in India.

The mechanical performance of LC^3 has proven to be quite encouraging and at par with existing cement standards. The ultimate strengths achieved (in MPa) are comparable to OPCs, with the strength development occurring at a rate greater than both OPC and PPC (when using the same clinker). Likewise, the durability of LC^3 has been observed to be better, or at least comparable, to both OPC and PPC. This is particularly true under severe conditions that are prevalent in marine environments and regions with alternate freezing and thawing cycles.

Key highlights of the LC^3 technology have been provided below:

- Typical LC^3 cements contain 40 to 65% clinker by weight, 30 to 38% calcined clay, 15 to 20% crushed non-cement grade limestone and 3 to 7% gypsum
- LC^3 has a clinker-to-cement ratio between 50 to 60%, considerably less than OPC (at 90 to 95%)
- CO_2 emissions lowered by up to 30%, compared to existing cements, during the production process
- The strength and durability of LC^3 is at par or greater than existing cement varieties

Benefits of LC^3

Due to the lower clinker content, the LC^3 technology offers several benefits over OPC and fly ash based PPC, as mentioned below:

- More efficient resource utilisation due to reduced clinker factor and usage of moderate quality limestone and clays
- Lower production energy requirements and reduced fuel usage
- CO_2 emissions lowered by up to 30%, compared to existing cements, during the production process
- Similar strengths and improved durability compared to traditional cement varieties
- Lower production cost compared to traditional cement varieties

CHAPTER 3

The Study

Objectives

Through scenario building (based on secondary research and data analysis) ascertain whether future uptake of LC^3 in India's overall cement production mix will result in potential net positive impacts on the environment and sustainable resource utilisation.

Scope

This study integrates use of non-critical resource alternatives that are both abundantly available and have a reduced environmental impact. These alternatives can help create Low Carbon Pathways (LCPs), by offering sustainable routes for satisying future demand for cement and its derivatives. The current study involves building LCPs and evaluating their future environmental and resource impacts against a Baseline Scenario, which is an extension of the business-as-usual practice. Through this, the study aims to determine the efficacy of the low-carbon initiative and further provide inputs for developing effective policy and regulatory framework in the country.

i. The geographical scope of the study is India

ii. The technical scope of the study is confined to the cement production process only, i.e. gate-to-gate considerations

Methodology and Approach

Methodology

The various activities performed to evaluate options through scenario building in the study have been outlined in the Figure 10.

Figure 10: Stepwise methodology adopted for conducting study

ACTIVITY 1
Secondary research and data collation

Task 1: Perform a detailed secondary research of the past, present and future circumstances of the global and Indian cement market

Task 2: Gather and organise all relvant information/data obtained through the above task

ACTIVITY 2
Scenario building

Task 1: Create a framework of inputs/assumptions based on relevant data/information obtained in Activity-1

Task 2: Formulate BAU and LCP scenarios based on the above framework

Task 3: Identify key indicators for enabling comparison of both scenarios

ACTIVITY 3
Perform calculations

Task 1: Carry out evluation of indicators for multiple scenarios with introduction of LC^3 in the Indian cement mix

ACTIVITY 4
Analysis and Interpretation

Task 1: Make a comparative analysis of the quantification of the indicators, between multiple scenarios

Task 2: Provide conclusions on the outcomes of the above analysis

ACTIVITY 5
Gather feeback on results

Task 1: Collate and submit results to external project partners in a draft project report, for inviting their suggestions and feedback

ACTIVITY 6
Prepare final results for publishing

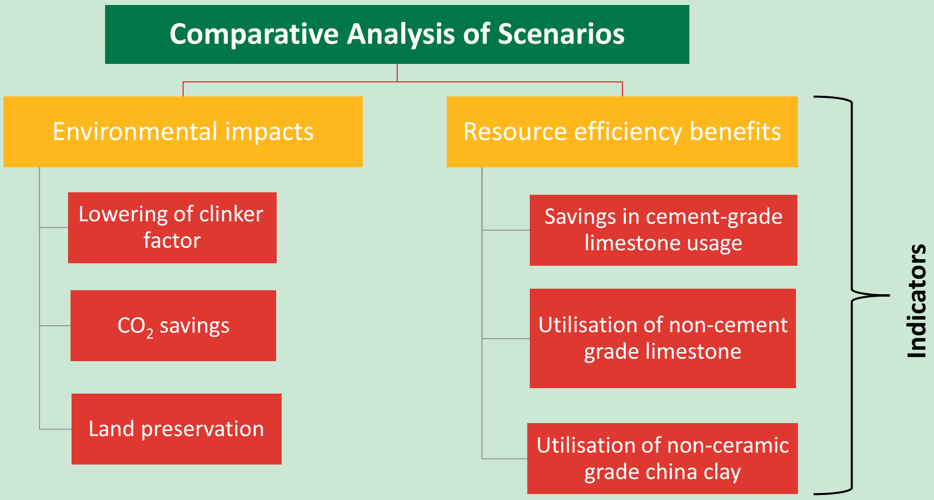
Task 1: Incorporate all suggestions feedback received and prepare final results

Task 2: Publish final results in a project report for wide distribution

Approach

In order to ascertain the net-positive effects due to introduction of LC[3], a comparative analysis of the environmental and resource performance has been carried out between two distinct cement production scenarios, termed as Business As Usual (BAU) and Low-Carbon Pathway (LCP) scenarios. The period of performing the analysis is twenty-five years, i.e. from 2022 to 2047. The LCP scenario is further segregated into three distinct sub-scenarios namely LCP1, LCP2 and LCP3, involving varying uptake of LC[3] in the Indian cement mix. Comparing the BAU scenario with one LCP sub-scenario constitutes a single assessment. The performance of the scenarios will be assessed on the basis of quantification of established indicators which have been listed in Figure 11 below.

Figure 11: Established indicators for assessing performance



Two distinct cement production scenarios

Business As Usual (BAU) Scenario:

The BAU scenario is essentially an extension of the prevailing cement scenario in the country till 2047. The trajectory of overall cement production shall follow the projections created by NITI Aayog which envisage production of around 1,042 million tonnes of cement by the year 2047. Characterised as a base scenario, BAU involves continued production of the three dominant existing cement varieties in India (namely PPC, OPC, and PSC) between the period 2022-2047.

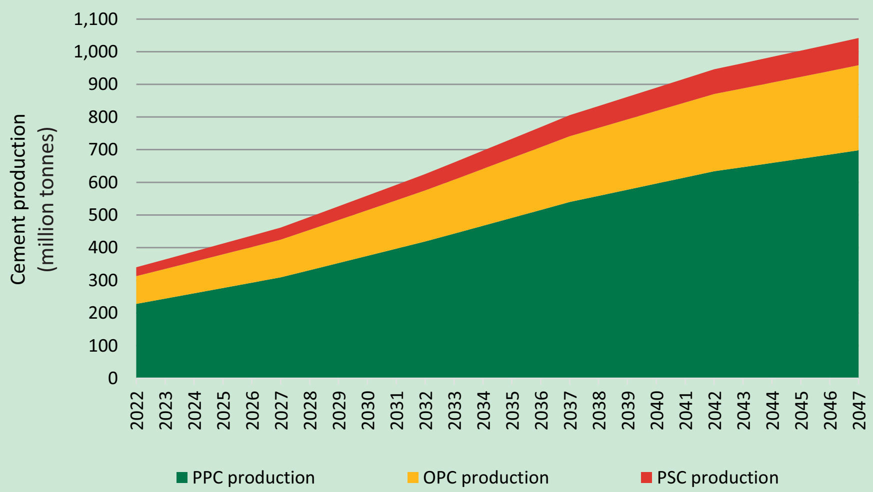
It is assumed that the Indian cement production mix will be identical to the current scenario and remain unchanged throughout the assessment period (2022-2047). Thus, the percentage contribution of PPC, OPC and PSC in total cement production will stay at 67%, 25% and 8% respectively. This translates into a cumulative production of 12,282 million tonnes of PPC, requiring nearly 3,070 million tonnes of fly ash over the entire assessment period. Although the share of coal in India's electricity mix will gradually fall, it will continue to play a dominant role until 2047 [12]. This will ensure sufficient generation of fly ash in the country thereby fully catering to the expected demand for PPC production. Moreover, in this scenario, contributions from other cement varieties (white cement, rapid hardening cement etc.), which remains minimal at present, will not be considered. Based on the above assumptions, this scenario becomes unsustainable. Keeping along the pathway envisaged under this scenario will result in a huge increase in country wide GHG emissions, overexploitation of critical natural resources (like limestone) and degradation of large swathes of protected areas. The essential features of the BAU scenario have been provided below:

Business As Usual (BAU) Scenario - Key Highlights

- Business As Usual (BAU) is seen as an extension of the prevailing cement production scenario in the country, from 2022 to 2047
- BAU involves production of three main cement varieties viz. PPC, OPC and PSC only
- Percentage contribution of PPC, OPC and PSC to cement production will remain constant over the duration of the scenario at 67%, 25% and 8% respectively

The variety-wise cement production trend (between 2022 to 2047) for BAU has been illustrated in Figure 12 below.

Figure 12: Cement production trend in India - BAU



Low Carbon Pathway (LCP) Scenarios:

Low Carbon Pathway (LCP) scenarios are envisaged as feasible alternatives to the BAU scenario, over the same duration, i.e. 2022-2047. The trajectory of overall cement production shall follow the BAU. The key differentiator between the BAU and LCP scenarios is the introduction of LC^3 along with the three main cement varieties (PPC, OPC and PSC). The 'overarching' LCP scenario has been further divided into three distinct sub-scenarios namely, LCP-1, LCP-2 and LCP-3. Each of the three LCP scenarios consider uptake of LC^3 production in India's overall cement mix starting from 2022 (the zero year), to varying degrees to reach different levels of saturation. The production of LC^3 is gradually scaled up to obtain a certain percentage share by the year 2035, which is then projected to remain constant till 2047. The extent to which LC^3 penetrates the cement mix by 2035 is different for each sub-scenario, increasing from LCP-1 to LCP-3. The contribution of LC^3 in LCP-1, LCP-2 and LCP-3 is 15%, 33% and 50% respectively. This translates into a cumulative production of 2,384, 5,240 and 7,937 million tonnes of LC3 in LCP-1, LCP-2 and LCP-3 respectively. Such levels of production will accordingly require nearly 715, 1,572 and 2,381 million tonnes of china clay over the entire assessment period. Irrespective of the projected scenario and based on latest data from Indian Bureau of Mines, India has sufficient reserves of china clay resources to fully cater to the expected demand for LC^3 production.

Summaries of the essential features of each LCP sub-scenario have been provided below:

Low Carbon Pathway-1 (LCP-1) Scenario - Key Highlights

- LC^3 consumes the market share of OPC only
- Total percentage share of LC^3 in overall cement mix by 2035 will be 15% and stay constant thereafter till 2047
- PPC and PSC percentage shares to be at 67% and 8% respectively, OPC to reduce to 10% by 2035 and stay constant till 2047

Low Carbon Pathway-2 (LCP-2) Scenario - Key Highlights

- LC^3 consumes the market share of both OPC and PPC
- Total percentage of LC^3 in overall cement mix by 2035 will be 33% and stay constant thereafter till 2047
- PSC percentage share to be 8%, OPC to reduce to 10% by 2035 and stay constant thereafter; balance shall be PPC

Low Carbon Pathway-3 (LCP-3) Scenario - Key Highlights

- LC^3 consumes the market share of both OPC and PPC
- Total percentage of LC^3 in overall cement mix by 2035 will be 50% and stay constant thereafter till 2047
- PSC percentage share to be 8%, OPC to reduce to 10% by 2035 and stay constant thereafter; balance shall be PPC

In the zero year, the starting percentage shares of PPC, OPC and PSC will be 67%, 25% and 8% respectively, same as BAU scenario. However, the percentage shares for PPC and OPC will not stay constant, which is a deviation from the BAU scenario. This is due to the introduction of LC^3 in the cement mix. For PPC, the percentage share will decrease in LCP-2 and LCP-3 only, as in LCP-1 LC^3 attains the terminal value of 15% by consuming share of just OPC in the overall mix. Thus, OPC percentage share will decrease in all sub-scenarios to 10% by 2035 and stay constant thereafter till 2047. In line with BAU, PSC will have a share of 8% that will remain constant throughout the period. Moreover, the starting percentage share of LC^3 in the overall cement mix in India will be 1%, which will be based on the type of sub-scenario (i.e. LCP-1, LCP-2 or LCP-3). It should be noted that LC^3 production will only start from 2023 (first year), although the period of assessment starts from the zero year.

The variety-wise cement production trend for all three LCPs have been illustrated below in Figures 13, 14 and 15.

Figure 13: Cement production trend in India – LCP1

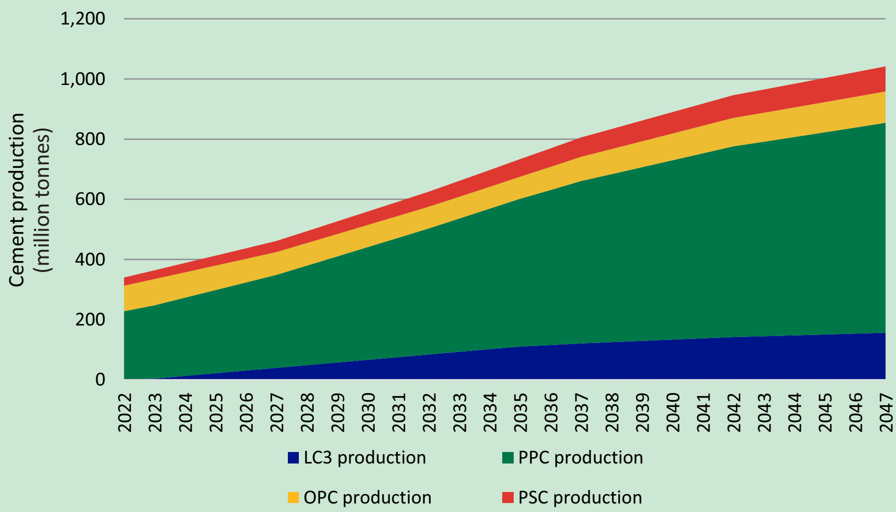


Figure 14: Cement production trend in India – LCP2

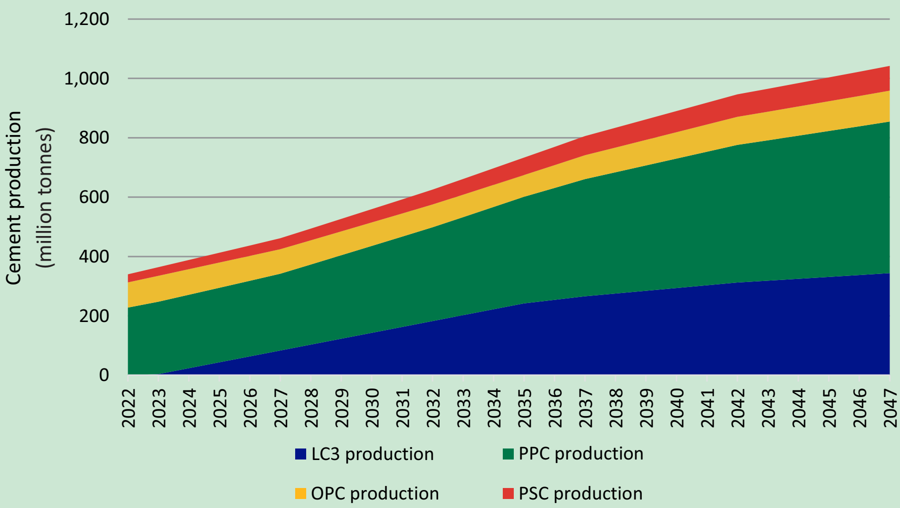
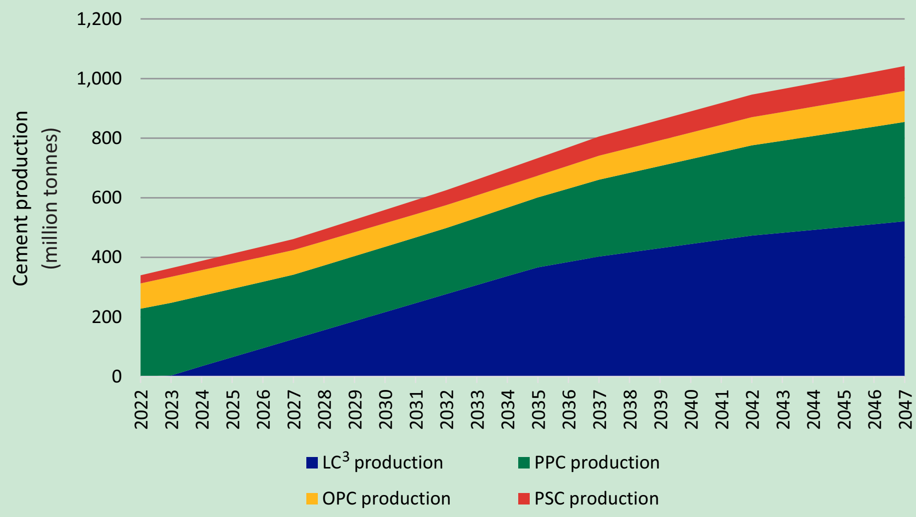


Figure 15: Cement production trend in India – LCP3



The cement mix is expected to gradually evolve from the existing set-up based on the share of each cement variety in the total production.

Results

CHAPTER 4

This section contains the results obtained by carrying out the study described in the preceding section.

Summary of Results

The results of the comparative analysis of LCP sub-scenarios with BAU (between the period 2022-2047) have been summarised in the Table 2 below.

Table 2: Summary of results obtained

Parameters	Indicators	in the year 2047 (compared to BAU)			Cumulative values (from 2022-2047)		
		LCP-1	LCP-2	LCP-3	LCP-1	LCP-2	LCP-3
Environmental Impacts	Lowering of clinker factor	64.4%	61.6%	59.0%			
	CO_2 savings (million tonnes)	50.6	65.8	80.2	777	995	1221
	Land preservation (hectares)	1,160.5	1,779.5	2,364.0	17,816	26,982	36,010
Resource Efficiency Benefits	Saving in cement-grade limestone usage (million tonnes)	105.5	161.8	214.9	1,620	2,453	3,274
	Non-cement grade limestone utilisation (million tonnes)	23.5	51.6	78.2	361	786	1191
	Non-ceramic grade china clay utilisation (million tonnes)	46.9	103.2	156.3	720	1,572	2,381

Detailed Results

The results pertaining to each indicator have been discussed below in detail.

Environmental Impacts

The environmental performance of BAU and LCPs has been compared by quantifying the established indicators for both scenarios. The indicators are:

i. Lowering of cinker factor

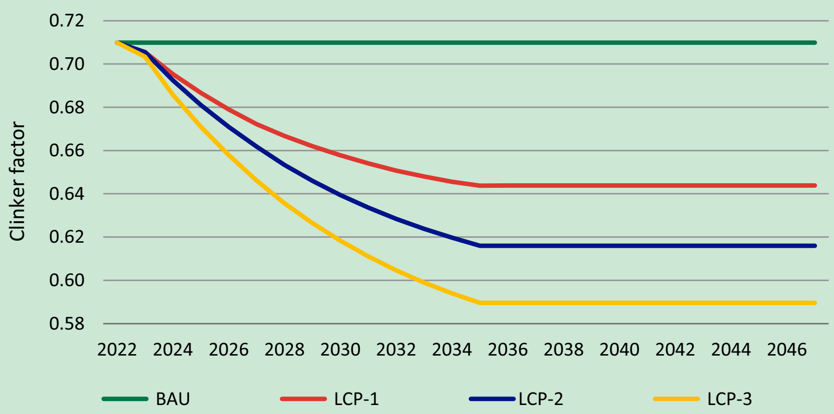
ii. CO_2 savings

iii. Land preservation

Lowering of clinker factor

The figure below illustrates the trend in the clinker factor in India for all the scenarios within the assessment period, i.e. 2022 to 2047. As expected, all scenarios have the same starting value of 0.71 as clinker factor; which evolves to attain varying values by 2047. For BAU, the clinker factor will remain constant at 0.71 throughout the assessment period. In comparison, all LCPs exhibit significant reductions in the clinker factor by the terminal year 2047. For LCP-1, the clinker factor reduces by 10% to become 0.64 in 2047. For LCP-2, the clinker factor shows a larger reduction of 13%, reaching a value of 0.62 in the terminal year. The reduction of clinker factor is most significant in LCP-3, amounting to 17%, resulting in a final value of 0.59. Figure 16 provides a forecast trend in the average clinker factor, year wise for all LCPs between 2022 and 2047.

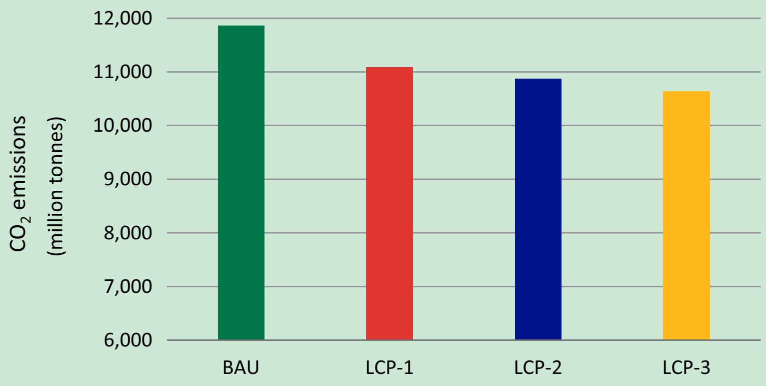
Figure 16: Forecast trend in average clinker factor



CO_2 savings

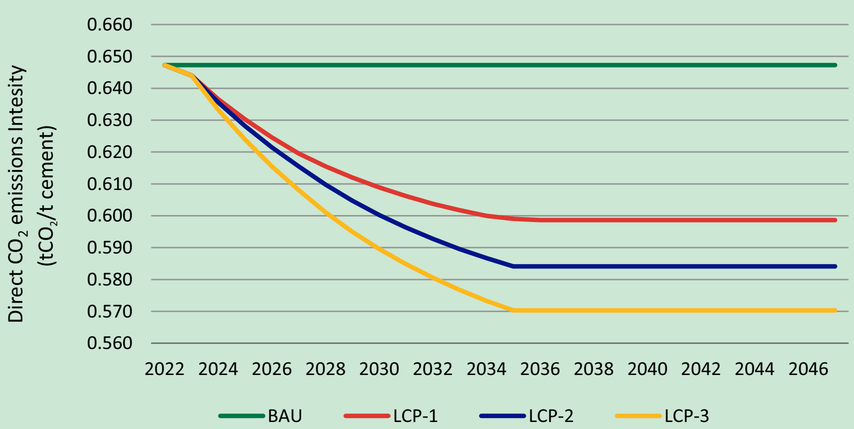
The Figure 17 below provides a comparison of the cumulative CO_2 emissions generated in each of the four scenarios within the assessment period. In BAU, the cumulative CO_2 emissions are estimated to be 11,865 million tonnes till 2047. In contrast, the cumulative CO_2 emissions for LCP-1, LCP-2 and LCP-3 will be around 11,088, 10,870 and 10,644 million tonnes respectively.

Figure 17: Total CO_2 emissions in all scenarios



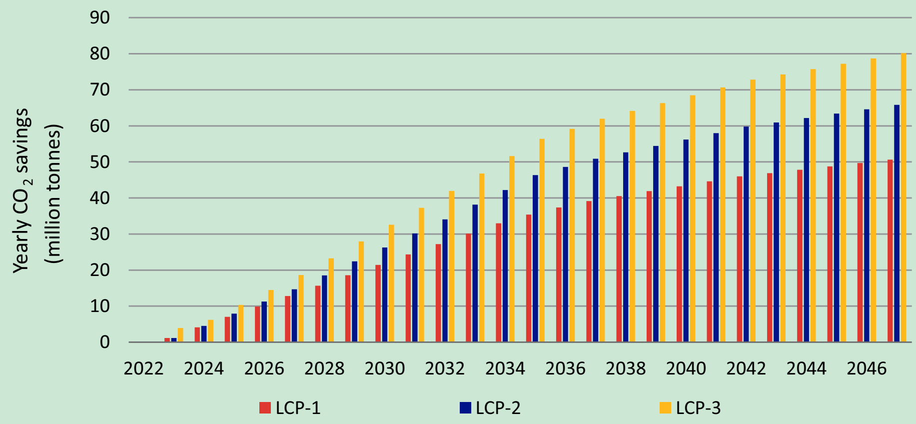
A comparison of the direct CO_2 emissions intensity of all scenarios has also been provided in the figure below. Not surprisingly, the graph obtained echoes the clinker factor evolution curve displayed above. This is attributed to the reasons outlined in Chapter-1. Moreover, as expected, all scenarios have the same starting value, of 0.65, which evolves on the basis of projected scenarios to attain varying values by 2047. For BAU, the direct CO_2 emissions intensity stays constant at 0.65 throughout the entire period. In comparison, all LCPs exhibit significant reduction in the emissions intensity by the terminal year 2047. For LCP-1, the emissions intensity reduces by 5.01% to become 0.60 in 2047. For LCP-2, the clinker factor shows a larger reduction, 7.01%, reaching a value of 0.58 tCO_2/t cement in the terminal year. Finally, the reduction of clinker factor is most in LCP-3, amounting to 8.34%, resulting in a final value of 0.57 tCO_2/t cement. Figure 18 provides a forecast trend in the direct CO_2 emissions intensity for all LCPs between 2022 and 2047.

Figure 18: Forecast trend in direct CO_2 emissions intensity



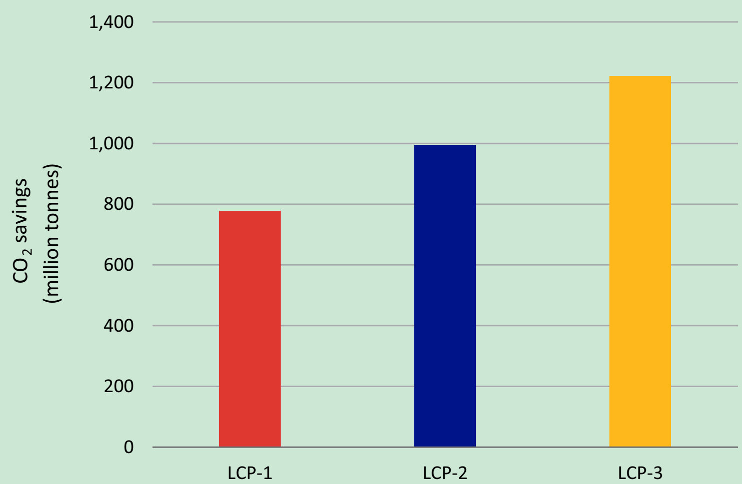
The corresponding annual savings in CO_2 emissions achieved by all LCP sub-scenarios (compared to BAU) have been illustrated in the figure below. The amount of CO_2 savings in the starting year are 1.2 million tonnes for LCP-1, LCP-2 and LCP-3. The trends showcase at a CAGR of 16.2%, 17.5% and 12.8% for LCP-1, LCP-2 and LCP-3, with the annual CO_2 savings in the terminal year estimated to be 50.6, 65.8 and 80.2 million tonnes respectively. Figure 19 provides a forecast trend in the yearly CO_2 savings for all LCPs between 2022 and 2047.

Figure 19: Forecast trend in yearly CO_2 savings



Finally, the cumulative CO_2 savings are shown below. Over the assessment period, the cumulative savings for LCP-1, LCP-2 and LCP-3 are estimated to be 777,995 and 1,221 million tonnes respectively. Figure 20 provides the cumulative CO_2 savings in all LCP sub-scenarios.

Figure 20: Cumulative CO_2 savings

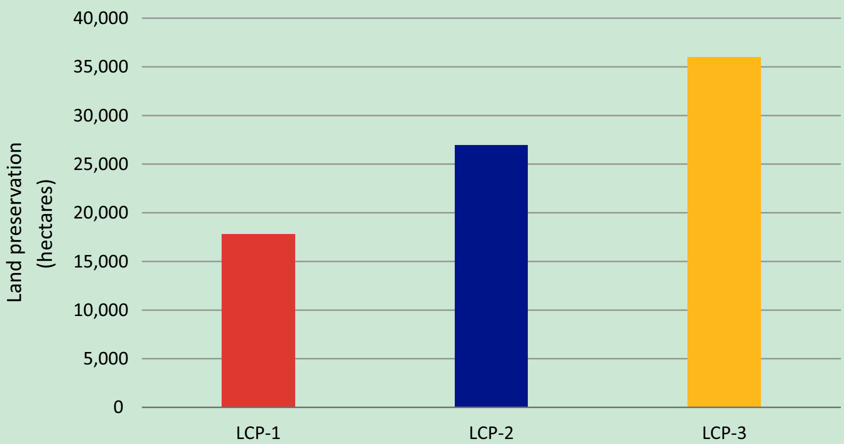


Land preservation

The LCPs result in preservation of land brought on by utilisation of non-cement grade limestone, which, in the absence of such progressive scenarios, would have been dumped on land adjacent to a limestone mine.

Figure 21 below provides the cumulative land preservation in all the LCP scenarios. Over the assessment period, the cumulative preservation due to LCP-1, LCP-2 and LCP-3 is estimated to be 178, 270 and 360 sq. km. respectively.

Figure 21: Cumulative land preservation



Resource Efficiency Benefits

The resource performance of BAU and LCPs has been compared by the quantifying the critical resource conservation and resource utilisation indicators for both scenarios. The indicators are:

i. Savings in cement-grade limestone usage
ii. Utilisation of non-ceramic grade china clay
iii. Utilisation of non-cement grade limestone

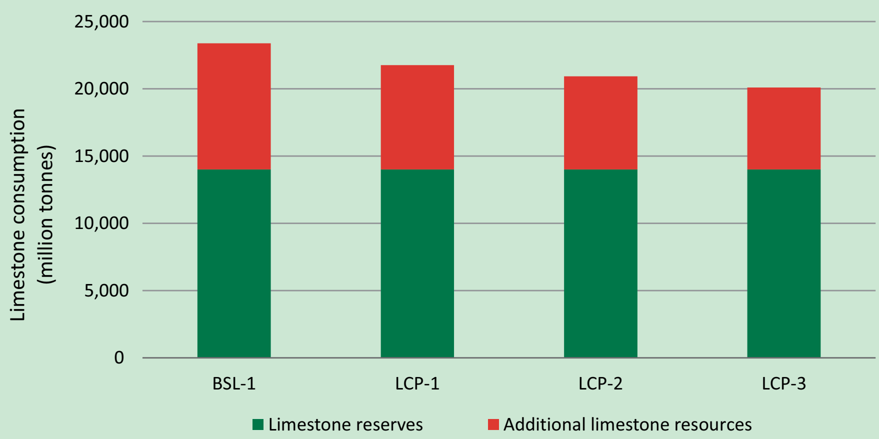
Each indicator has been discussed individually below.

Savings in cement-grade limestone usage

In BAU, the cumulative consumption is estimated to be 23,374 million tonnes till 2047. In comparison, the cumulative consumption for LCP-1, LCP-2 and LCP-3 will be around 21,754, 20,921 and 20,100 million tonnes respectively. Figure 22 below provides a comparison of the cumulative limestone consumption under all scenarios within the assessment period.

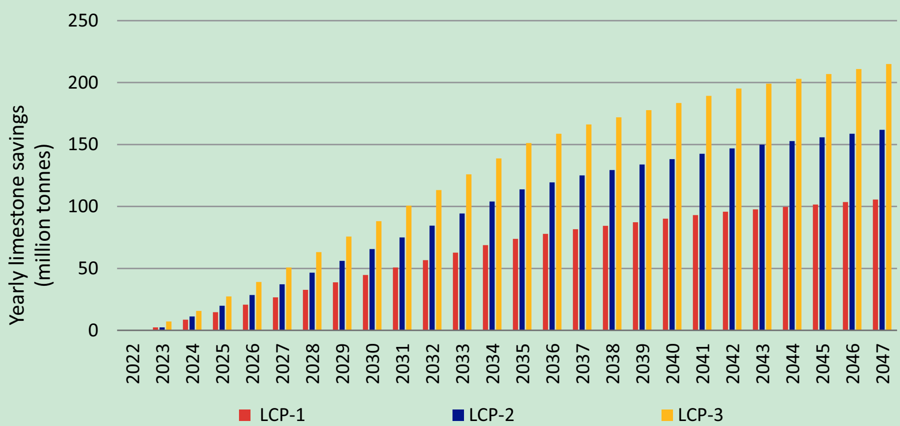
Also, as indicated, BAU will result in consumption of 9,370 million tonnes of additional limestone resources (or 40.1% of total consumption) which, at present, are not commercially accessible. In this scenario, additional mining in eco-sensitive zones would need to be undertaken to cater to 9.3 billion tonnes of cement-grade limestone. The introduction of LC^3 will require reduced exploration of additional limestone resources. For LCP-1 scenario, additional resources mined would be 7,750 million tonnes; for LCP-2 scenario, additional resources mined would be 6,917 million tonnes; for LCP-3 scenario, additional resources mined would be 6,096 million tonnes. In the best-case scenario, the additional limestone resources mined would be equivalent to 30.3% of the cumulative limestone requirements envisaged till the year 2047.

Figure 22: Cumulative limestone consumption



The corresponding annual savings in limestone consumption achieved by all LCP scenarios (compared to BAU) have been illustrated in the figure below. The amount of savings for the starting year are 2.46, 2.46 and 7.12 million tonnes for LCP-1, LCP-2 and LCP-3 respectively. The annual savings in the terminal year estimated to be 105.5, 161.8 and 214.9 million tonnes respectively. Figure 23 provides a forecast trend in the yearly limestone savings for all LCP scenarios between 2022 and 2047.

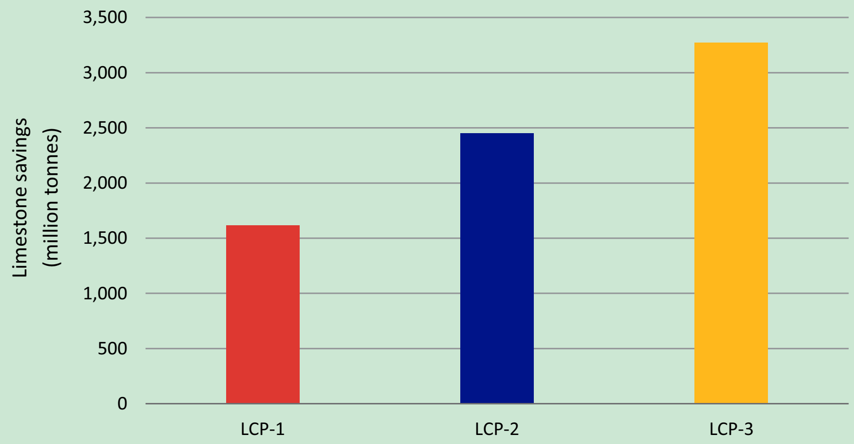
Figure 23: Forecast trend in yearly limestone savings



Over the assessment period, the cumulative limestone savings are shown below. The cumulative savings for LCP-1, LCP-2 and LCP-3 are estimated to be 1,620, 2,453 and 3,274 million tonnes respectively in comparison to BAU scenario.

Figure 24 provides the cumulative limestone savings in all LCP scenarios.

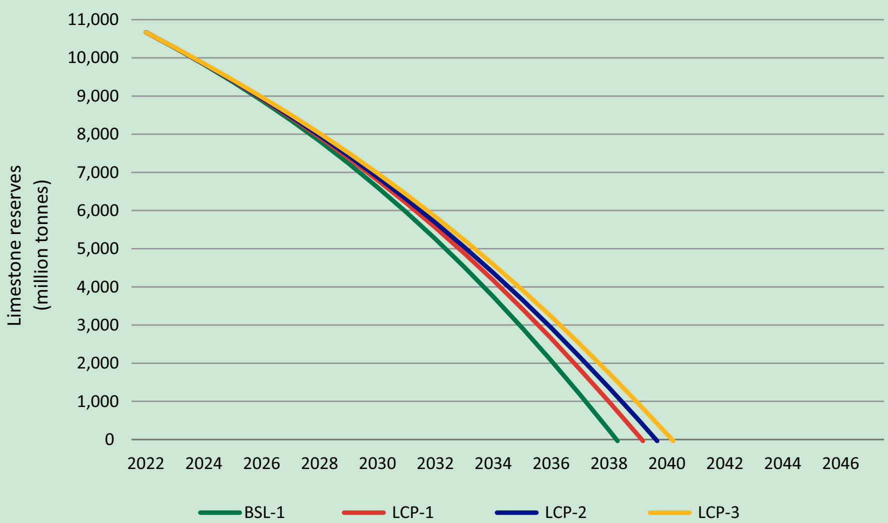
Figure 24: Cumulative limestone savings



Finally, based on the forecast trend in consumption of limestone, a comparison between all scenarios was performed with respect to the duration of the availability of limestone reserves. For BAU, at the calculated rate of limestone consumption, the known available limestone reserves will be exhausted by late 2038. In comparison, for LCP-1, the exhaustion is expected to happen by late 2039, while for LCP-2 and LCP-3 it is early and late 2040 respectively. Thus, the maximum possible delay in limestone exhaustion (when comparing BAU with LCP-3) is around two years. This means that even in the most aggressive LC^3 adoption scenario, the limestone will only be made available for an additional two years, i.e. till 2040 compared to 2038. Figure 25 provides a forecast trend for limestone reserves exhaustion that highlights the following:

- Need to conserve resources of cement-grade limestone
- Need to accelerate the substitution of cement-grade limestone and clinker with, for example, Kaolinitic clays
- Inevitable need for mining of additional cement-grade limestone resources; 9 billion tonnes for BAU scenario compared to 6 billion tonnes for best case (LCP-3) scenario.

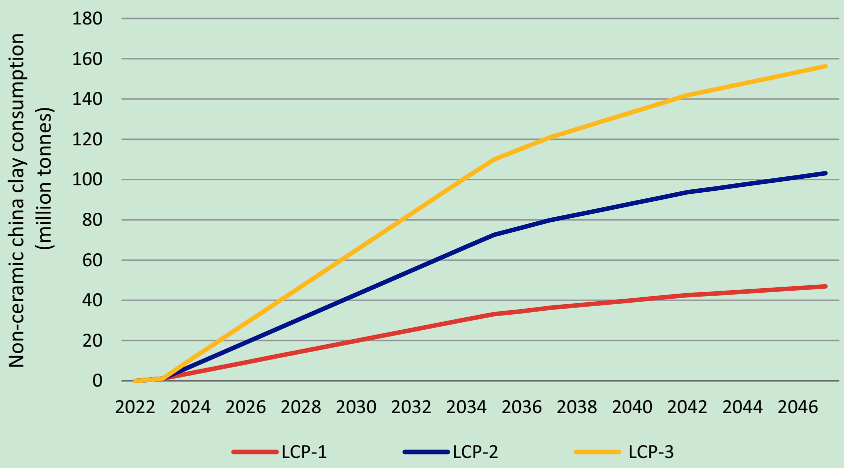
Figure 25: Forecast trend in limestone reserves exhaustion



Utilsation of non-ceramic grade china clay

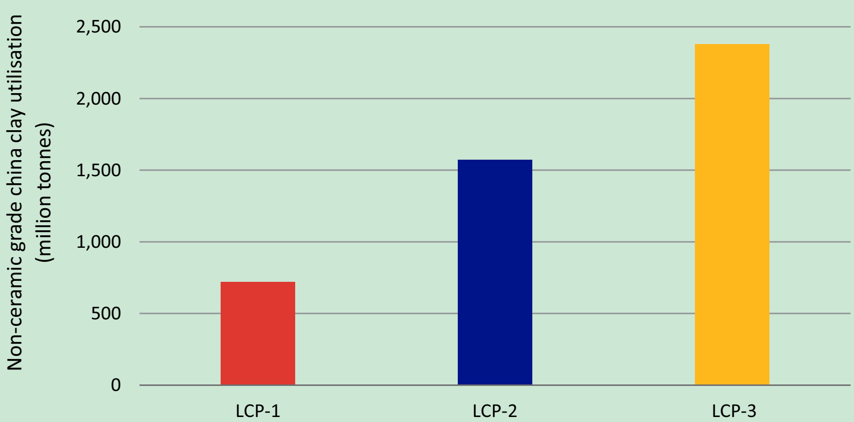
The amount of such china clay utilised in the starting year is 1.09 million tones for all LCPs. As expected, the three forecast trends also showcase CAGRs of 16.23%, 19.95% and 21.96%, with the annual china clay utilisation in the terminal year estimated to be 46.9, 103.2 and 156.3 million tonnes for LCP-1, LCP-2 and LCP-3 respectively. The forecast trend in annual utilisation of non-ceramic grade china clay achieved by all LCP scenarios have been illustrated in the Figure 26 below.

Figure 26: Forecast trend in non-ceramic grade china clay consumption



The cumulative non-ceramic grade china clay utilisation is shown below. Over the assessment period, the cumulative utilisation in LCP-1, LCP-2 and LCP-3 is estimated to be 720, 1,572 and 2,381 million tonnes respectively. Irrespective of the scenario, based on latest data from Indian Bureau of Mines, India has sufficient reserves of china clay to fully cater to the expected demand for LC^3 production. Figure 27 provides the cumulative non-ceramic grade china clay utilisation in all LCP scenarios.

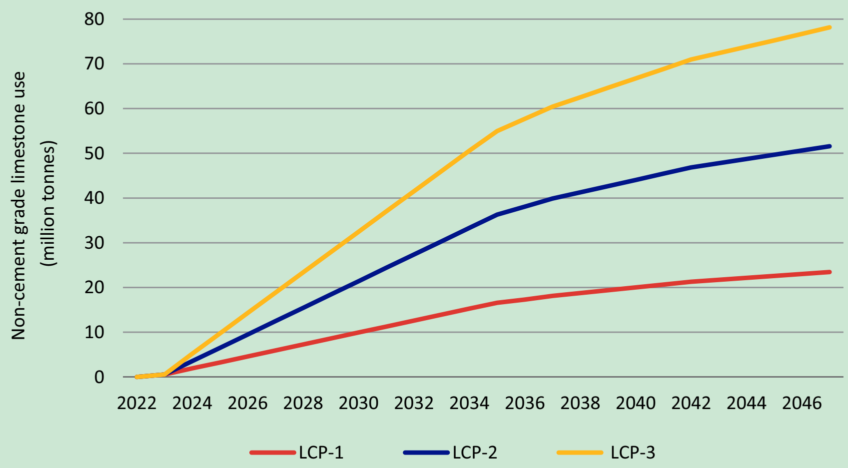
Figure 27: Cumulative non-ceramic grade china clay utilisation



Utilisation of non-cement grade limestone

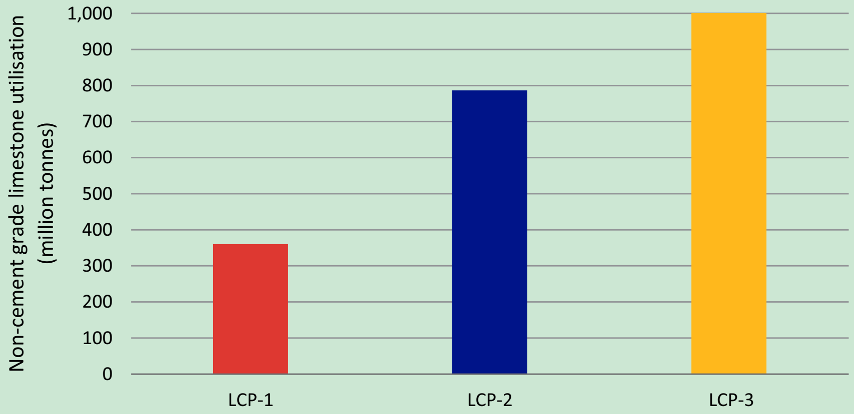
The annual utilisation of non-cement grade limestone achieved by all LCP scenarios (compared to BAU) have been illustrated in the figure below. The amount of such limestone utilised in the starting year is 0.55 million tonnes for all LCPs. As expected, the three forecast trends also showcase CAGRs of 16.23%, 19.95% and 21.96%, with the annual limestone utilisation in the terminal year estimated to be 23.45, 51.58 and 78.15 million tonnes for LCP-1, LCP-2 and LCP-3 respectively.

Figure 28: Forecast trend in non-cement grade limestone consumption



The cumulative non-cement grade limestone utilisation is shown below. Over the assessment period, the cumulative utilisation in LCP-1, LCP-2 and LCP-3 is estimated to be 360, 786 and 1,191 million tonnes respectively. Figure 29 provides the cumulative non-cement grade limestone utilisation in all LCP scenarios.

Figure 29: Cumulative non-cement grade limestone utilisation



Conclusions

CHAPTER 5

India's cement production is expected to undergo a phase of rapid expansion between 2020 with and 2050, following the projected growth in the country's construction sector. The country's cement production is estimated to grow to nearly 1,050 million tonnes by 2047, close to 300% increase from current production level. This inevitable expansion of the cement industry will lead to an increase in the carbon dioxide (CO_2) emissions to unsustainable levels, reaching 674 million tonnes by 2047 (25% of the total GHG emissions of the country at present). Apart from the above environmental implications, Business As Usual (BAU) growth will result in serious resource issues and divergence of compliance with national and international regulations. The current availability of cement-grade limestone is 14,000 million tonnes. It is projected that, by 2047, BAU scenario will require sourcing of nearly 9,400 million tonnes of additional limestone resources which, at present, are not commercially exploited and would require mining in eco-sensitive zones and inaccessible areas. Thus, it is evident that the pursuit of BAU will be unsustainable from both the environment and resource perspective.

Role of LC^3

Limestone Calcined Clay Cement (LC^3) is a blend of clinker with 30% calcined clay and 15% non-cement grade limestone and presents a potentially viable solution in addressing the looming environmental and resource crunch. LC^3 utilises medium grade Kaolinitic clays and limestone that is abundantly available in the country, thereby significantly reducing the clinker factor in cement production. Moreover, it contributes to 30% reduction in CO_2 emissions and is energy and cost effective. Lastly, LC^3 can be produced in a process compatible with OPC and PPC by integrating and blending with existing manufacturing equipment, leading to only marginally increased investments required for installation of calcining equipment. The introduction of LC^3 in India's cement mix has the potential to significantly enhance the environmental and resource performance in the country's cement sector. The scenario building with LC^3 cement becoming a significant constituent of the cement mix is presented in the Low Carbon Pathways (LCPs) roadmap.

Low Carbon Pathways (LCPs) Roadmap

The study has concluded that scenarios with introduction and growing proportion of LCPs have a better environmental and resource performance compared to BAU in all the established indicators. LCPs lead to a lowering of clinker factor and corresponding CO_2 emissions. The IBM data shows that the non-ceramic grade china clay is widely available in India, overlapping with existing cement plants and captive mines. Moreover, in terms of resource performance, LCPs generate a fair amount of limestone savings, support utilisation of non-cement grade limestone and non-ceramic grade china clay.

In this study, LCP-3 scenario presents the most aggressive pathway and involves highest penetration of LC^3 in the Indian cement mix. Thus, implementing the LCP-3 scenario would provide the highest environmental and resource benefits compared to BAU. Between 2022 and 2047, the cumulative CO_2 savings that would result from this scenario are 1,221 million tonnes, which is 45% of India's current GHG emissions. It is observed that the terminal value of the clinker factor for LCP-3 scenario will approach 0.59. This matches the target of 0.58 set up in the low carbon roadmap envisaged for sustainable production in India by WBCSD. In setting this sustainability target, WBCSD has considered five important levers (which does not include LC^3) that will help attain the targeted clinker factor value namely AFR, thermal and electrical efficiency, clinker substitution, WHR, and newer technologies. Thus, adoption and integration of LC^3 in the overall cement mix alone has potential to attain the same long-term sustainability performance which will be delivered by all of the 'low carbon' levers combined. In terms of resource performance, LCP-3 scenario would lead to a cumulative saving of 3,274 million tonnes of cement-grade limestone and utilisation of nearly 1,191 million tonnes of non-cement grade limestone. This cuts down the additional limestone resources to be, hitherto, prospected by 35% compared to BAU scenario. Lastly, it promotes utilisation of about 2,381 million tonnes of china clay; both of which are abundantly available in the country.

Call for an Early Action

Continuation of the BAU scenario will lead to severe effects on the environment and natural resources crunch by 2038. It is projected that in the ensuing decade till 2047, BAU scenario will require nearly 9,400 million tonnes of additional limestone resources which, at present, are not commercially accessible and would require mining in eco-sensitive zones. In the aggressive LCP-3 scenario, the introduction of LC^3 extends the utilisation of available limestone resources by three years. It further curtails the additional mined limestone resources to 6,100 million tonnes. This impending reality necessitates an early action which will involve an accelerated uptake of LC^3 in India's cement mix in order to ensure sustainable growth in the country.

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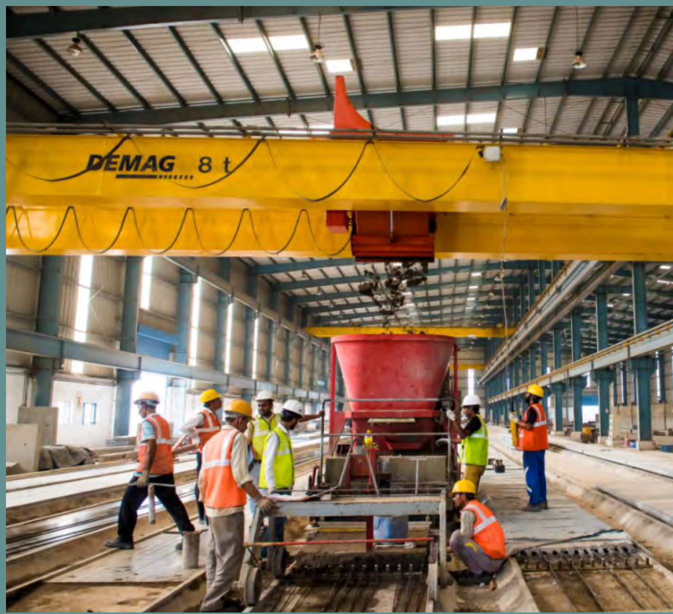
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ABOUT TARA

TARA

The Society for Technology & Action for Rural Advancement (TARA) is a social enterprise set up in the year 1985 at New Delhi, India. It is an "incubation engine" of the Development Alternatives Group which has been providing development solutions in India and elsewhere. The mission is Mission is to build capacity, incubate business models and manage processes to create economic, social and environmental value on a large scale. TARA as an “enabler”, is instrumental in the creation of livelihood support systems, training and capacity building for the rural poor and marginalised communities. TARA as an “aggregator” bundles support service packages, help large corporation explore new markets and aggregate the output of local producer groups including micro, mini and small enterprises and connect these groups to market opportunities for BOP access and market development for ethical products and services. Governments, large Corporations and Civil Society networks benefit from TARA’s expertise as a “manager” of large awareness creation, environmental action, community development and service delivery programmes in areas such as affordable housing, renewable energy, water management, sustainable agriculture, waste management and recycling.

TARA incubates ecologically efficient and economically viable solutions to meet basic needs, which addresses environmental challenges, with emphasis on clean technology. The major focus is on reducing environmental emissions and supporting resource efficient consumption and production systems. Technologies are developed in collaborative partnership with various national and international research organisations and institutes. These innovations are tested at laboratory, pilot and commercial scale to establish their viability and transform them into scalable business models ready to be adapted areas entrepreneurs and enterprises. Technologies process and value innovations are developed mainly for micro, small and medium enterprises, as well as for community groups. The focus is always on enhancing incomes and creating livelihood opportunities for individuals and communities. In the year 2017-2018, TARA has also initiated incubation of low carbon technologies in association with large companies to develop customised solutions for utilising wastes and transforming them into useful and marketable products, thereby supporting companies in reducing emissions and achieving global sustainability. The Technology Incubation team of TARA, in association with the Research and Product Development team of Development Alternatives, has been successful in creating interest in various countries, especially Africa and the Middle East on its developed low carbon technologies. Initiatives have been started for transfer of technical know-how to development organisations and commercial business units. Work on Technology Incubation covers four functional areas, viz. Green Building Materials, Waste Utilisation, Water Solutions and Clean Energy Services. It is supported by TARA's own labs, workshops, design studios and pilot production facilities at Delhi and Datia (Madhya Pradesh).

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