CII-ITC Centre of Excellence for Sustainable Development

CII
Confederation of Indian Industry

Greenhouse gas mitigation across the cement value chain

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List of Abbreviations

ANFO	-	Ammonium Nitrate Fuel Oil
BEVs	-	Battery Electric Vehicles
BIM	-	Building Information Modelling
BIS	-	Bureau of Indian Standards
BYF	-	Belite-Ye'elimite-Ferrite
C&D	-	Construction and Demolition
C4AF	-	Tetracalcium Alumino-Ferrite
$CaCO_3$	-	Calcium Carbonate
CH_4	-	Methane
CMA	-	Cement Manufacturers Association
CO_2	-	Carbon dioxide
CPCB	-	Central Pollution Control Board
CPP	-	Captive Power Plant
CSA	-	Calcium Sulfoaluminate
EF	-	Emission Factor
EVs	-	Electric Vehicles
FAKS	-	Fluidized-bed Advanced cement Kiln System
FCEVs	-	Fuel Cell Electric Vehicles
GHG	-	Green House Gas
GWP	-	Global Warming Potential
HDVs	-	Heavy Duty Vehicles
IPCC	-	Intergovernmental Panel on Climate Change
IPPU	-	Industrial Processes and Product Use
IRP	-	International Resource Panel
ITC-HS	-	Indian Trade Clarification Harmonized System
LC3	-	Limestone Calcined Clay Cement
N_2O	-	Nitrous Oxide
NOx	-	Nitrogen Oxides
OPC	-	Ordinary Portland Cement
PPC	-	Portland Pozzolana cement
PSC	-	Portland Slag Cement
RDF	-	Refuse-derived Fuel
SCM	-	Supplementary Cementitious Material
SPCB	-	State Pollution Control Board
US EPA	-	United States Environmental Protection Agency

Chapter 1: Introduction

Background

The earth's climate has always been changing, going through several warm and cool phases over the millennia. These phases were due to natural causes and lasted for long periods of time. Today however, the climate is changing at an unprecedented rate. Global temperature is rising rapidly due to an increased concentration of greenhouse gases in the atmosphere, a phenomenon that is now thought to be unequivocally caused by human activities. Reports by the Intergovernmental Panel on Climate Change (IPCC) indicate that anthropogenic GHG emissions during 2010-2019 were higher than any previous time in human history,[1] causing global surface temperatures in 2011-2020 to be 1.09°C higher than that in the period 1850 to 1900.[2] This increasing temperature is manifesting itself in the form of extreme weather events across the world - extreme heatwaves, raging floods, severe droughts, rising sea levels and irregular precipitation patterns.

Countries across the world have pledged to take action to reduce emissions of greenhouse gases. The Paris Agreement, a legally binding international treaty on climate change, was adopted in 2015 by 196 countries. It aims to limit global temperature rise in this century to 2°C, while pursuing efforts to further limit this rise to 1.5°C.[3] Subsequent to the ratification of the Paris Agreement, several countries have announced their intention to achieve net-zero emissions by 2050, including China, the United States of America and the European Union.[4,5] Businesses are pledging to reduce emissions through different strategies such as switching to renewable energy, switching their fleets to electric vehicles or working towards deforestation-free supply chains.

Despite all these initiatives, the impacts of climate change are persistent and more pronounced than before which can be seen in the form of increasing extreme weather events such as heatwaves and floods. Progress on climate action has been very slow compared to the rate at which progress is required to limit these impacts of climate change. The IPCC special report on global warming of 1.5°C states that the 1.5°C target set by the Paris Agreement will most likely be exceeded between 2030 and 2052 if warming continues at the current rate.[6] This indicates that we must go beyond what is already being done and explore all possible avenues for mitigating climate change.

Resource efficiency in climate change mitigation

Much of the action taken to reduce greenhouse gas emissions, globally and in India, has revolved around increasing energy efficiency in manufacturing processes and the product-use stage. This is

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[1] IPCC (2022). Technical Summary. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_TechnicalSummary.pdf

[2] IPCC (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

[3] The Paris Agreement https://www.un.org/en/climatechange/paris-agreement

[4] Climate Watch: Net-zero tracker. https://www.climatewatchdata.org/net-zero-tracker Accessed on 10 September 2021

[5] European Commission (2019). The European Green Deal, COM/2019/640

[6] IPCC (2018). Summary for Policymakers. In: Global Warming of 1.5°C. Available at https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

because improving energy efficiency is considered the most economically viable means of reducing emissions and hence is a shared policy goal of many governments across the world.[7]

While increased energy efficiency can achieve significant emission reduction, its benefits have plateaued out over the years. Existing energy requirements in several industrial processes are close to the thermodynamic limit, reducing opportunities for further energy efficiency. This limitation drives the need for comprehensively examining other forms of efficiency which will help reduce emissions, especially using the life cycle approach based on the systems perspective. Material efficiency is one such avenue which has great potential for reducing environmental impacts of several industrial processes. The few studies that emphasize the need for increased material efficiency focus mainly on the manufacturing stage. While this stage may often be the stage that generates most emissions, it is necessary to expand the scope to cover the entire product life cycle in order to tap all possible avenues of reducing emissions.

According to the International Resource Panel's (IRP) Global Resources Outlook report, extraction and processing of natural resources such as biomass, fossil fuels, metal ores and non-metallic minerals makeup to about 50% of total global greenhouse gas emissions.[8] IRP's 2017 report on Resource Efficiency indicates that if we combine resource efficiency with climate policies, greenhouse gas emissions can be reduced by 20%.[9] Materials efficiency strategies will help in efficient management of resources, and reduce the demand for production of new materials. Reduced material demand will lessen the extraction of natural resources, and result in energy savings and emissions reduction. It will also reduce the dependence of imports and make countries self-reliant. [10]

The IRP has identified the following material efficiency strategies for climate change mitigation: using less material by design, material substitution, fabrication yield improvements, more intensive use, enhanced end of life recovery and recycling, recovery, remanufacturing or reuse of components, and product lifetime extension.[11]

Resource efficiency in the cement value chain

The greatest decarbonization challenge lies in sectors where industrial processes require high temperature heat and/or where the processes/chemical transitions involve CO_2 emissions. These sectors are commonly termed hard-to-abate sectors and include heavy industries (cement, steel, and plastics) and heavy-duty transport (heavy-duty road transport, shipping and aviation) sectors. With an increase in the economic activity across the world, the demand for basic materials such as

[7] IEA (2008). Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis. Available at https://iea.blob.core.windows.net/assets/68742ff1-b01f-4fbe-834d-936b8d23064a/WorldwideTrendsinEnergyUseandEfficiency.pdf

[8] IRP (2019). Global resources outlook 2019: Natural Resources for the Future We Want. Available at: https://www.resourcepanel.org/reports/global-resources-outlook

[9] UNEP (2017). Resource Efficiency: Potential and Economic Implications. A report of the International Resource Panel. Available at: https://www.resourcepanel.org/sites/default/files/documents/document/media/resource_efficiency_report_march_2017_web_res.pdf

[10] Allwood, J. M., et al., (2013). Material efficiency: providing material services with less material production. Philosophical Transactions of the Royal Society. Doi: http://dx.doi.org/10.1098/rsta.2012.0496

[11] IRP (2020). Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future. Available at: https://www.resourcepanel.org/reports/resource-efficiency-and-climate-change

cement and steel will only increase. Globally, the hard-to-abate sectors account for 30% of CO_2 emissions and these are expected to rise to 16 Gt by 2050 if current trends continue.[12]

It is thus relevant to examine resource efficiency opportunities in hard-to-abate sectors for climate mitigation. It is estimated that adoption of circular economy frameworks such as lighter designs, improved yields, more intensive use, product sharing, and increased recycling can reduce emissions by 56% from the production of cement, steel, aluminum and plastics.[13]

As the world's second largest producer of cement, a focus on the cement value chain as a whole will help quantify and tackle emissions from two hard-to-abate sectors, cement manufacture and heavy-duty transport. Taking the first step in using the value-chain approach, this report aims to

1. establish a baseline using which the abatement potential arising from improvements to energy efficiency and material efficiency across the value chain can be identified
2. identify opportunities for use of technology to improve efficiency (energy and material)

Detailed descriptions of opportunities for applying technology to improve the material and energy efficiency of waste heat recovery systems are presented, as is an account of carbon capture and use/storage in the cement industry worldwide, with recommendations for the Indian context.

[12] ETC (2018). Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century. Available at: https://www.energy-transitions.org/publications/mission-possible/#:~:text=The%20report%20Mission%20Possible%3A%20Reaching,60%25%20by%20mid%2Dcentury%20as

[13] Material economics (2018). The Circular Economy - a Powerful Force for Climate Mitigation. Available at: https://materialeconomics.com/publications/the-circular-economy-a-powerful-force-for-climate-mitigation-1

Chapter 2: The cement value chain in India

India is urbanizing at an unprecedented rate, with its urban population estimated to nearly double between 2018 and 2050.[14] This rapid growth is directly linked with increasing infrastructure demand to cater to the growing population. The Government of India is focusing on developing infrastructure through several flagship projects and schemes across different sectors such as the *Pradhan Mantri Awas Yojana* (Housing for All) and the National Smart Cities Mission. Increased remote work due to the COVID-19 pandemic has also increased demand for affordable housing. The cement industry lies at the heart of this infrastructure development and is one of the eight core industries of the economy (coal, crude oil, natural gas, refinery products, fertilizers, steel, and electricity being the others).[15]

India is the second largest producer of cement in the world, with an installed capacity of nearly 557 MT and production levels reaching 337 MT in 2018-19.[16] Installed capacity and production levels have grown at 10% and 6% per annum over the last 13 years. The capacity utilization has been around 60% to 90%. The demand for cement is expected to reach 550 to 600 MT per annum by 2025.[17]

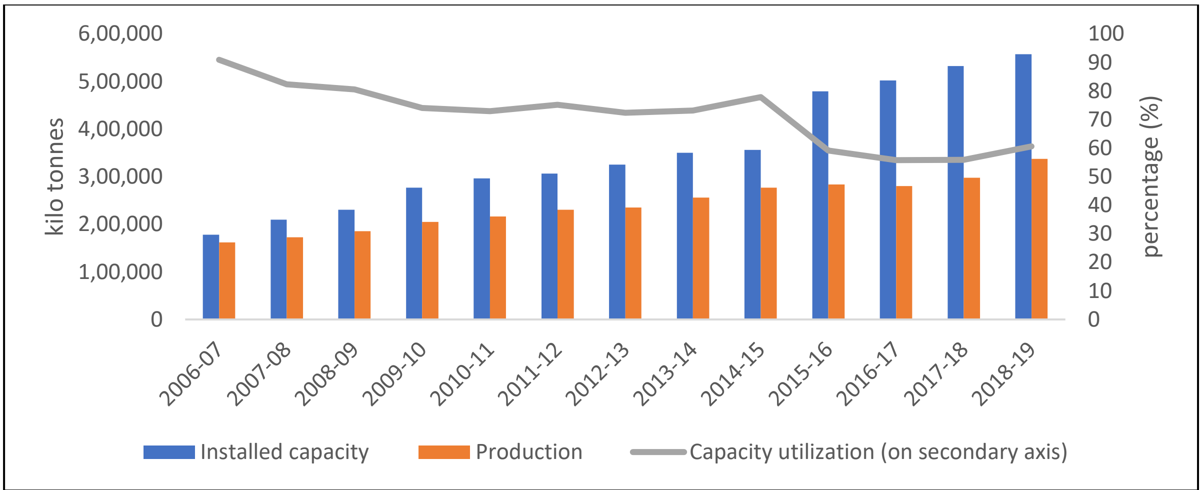

Figure 1: Installed capacity, cement production and capacity utilization in India between 2006-07 and 2018-19[18]

It is clear that the cement sector will continue to grow as population and demand for buildings and infrastructure go up. To reduce consumption and greenhouse gas emissions, it is important to view cement as a product across its lifecycle: this approach will help identify the potential for efficiency improvements at all lifecycle stages, beyond measures related to energy use and the cement manufacturing process. Cumulative benefits can be expected in terms of resource consumption and GHG emissions.

[14] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations. Available at: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

[15] Department for Promotion of Industry & Internal Trade (2021). Annual Report 2020-21. Available at: https://dpiit.gov.in/sites/default/files/annualReport-English2020-21.pdf

[16] Indian Bureau of Mines (2020). Indian Minerals Yearbook 2019 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=1474

[17] IBEF (2021). Indian Cement Industry Analysis. Available at: https://www.ibef.org/industry/cement-presentation

[18] Production and capacity data obtained from various issues of the annual Indian Minerals Yearbook published by the Indian Bureau of Mines. Refer to Annex 4.1 for detailed sources.

The cement value chain is therefore examined across extraction, manufacturing, distribution, in-use and end-of-life (Figure 2). Transport is an important activity required at all points in the product life cycle – in this report, 'transport' refers movements within a particular lifecycle stage, while 'distribution' refers to transport between lifecycle stages.

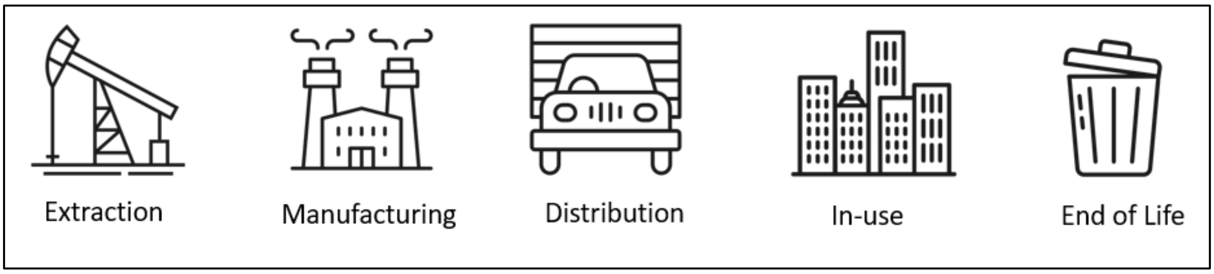

Figure 2: The cement value chain

Each point of the value chain is associated with stakeholders whose actions and decisions influence the choices made at each step, thereby directly or indirectly affecting GHG emissions in the cement life cycle or value chain: identifying these stakeholders stage-wise is important.

- Extraction: This stage involves extraction and processing of raw materials required to produce cement. Most cement plants in India are located close to limestone reserves (primary raw material) and operate captive coal mines under Government permission.[19] Other raw materials (such as gypsum, iron ore, silica, bauxite, fly ash and slag) and energy sources (such as petcoke) are extracted and transported to manufacturing sites by rail and road. Stakeholders at this stage include the Indian Bureau of Mines, Ministries of Power and Steel, Ministry of New and Renewable Energy and raw material manufacturers such as Rajasthan State Mines and Minerals, Bharat Aluminum Co. Ltd., UltraTech Cement Ltd., and Coal India Limited.
- Manufacturing: This stage involves production of cement and stakeholders include around 145 cement producers in the country.[20] Other stakeholders at this stage include the Bureau of Indian Standards, Ministry of Environment and Climate Change, Central Pollution Control Board (CPCB), State Pollution Control Boards (SPCBs), cement manufacturing equipment manufacturers and suppliers, Cement Manufacturers Association, and the Ready Mixed Concrete Manufacturers' Association.

Table 1: Major cement manufacturers in India

	Company	Market share (%)	Number of plants
1	UltraTech Cement	31	59
2	Ambuja Cement	21	13
3	ACC Limited	12	97
4	Shree Cement Limited	10	12
5	Dalmia Bharat	8	13
6	Birla Corporation Limited	5	10
7	India Cement Limited	5	10
8	The Ramco Cement Limited	4	12

[19] Indian Bureau of Mines (2020). Indian Minerals Yearbook 2019 (Part- III: MINERAL REVIEWS) - Cement. Available at: https://ibm.gov.in/writereaddata/files/07072020143800Cement_2019.pdf
[20] DPIIT, (2020). Company-wise list of cement plants. Cement Information System. Available at: https://eaindustry.nic.in/cement/report2.asp

- Distribution: This stage includes the distribution of cement to wholesalers, retailers and end-users such as concrete manufacturers and infrastructure companies. The main stakeholders here are the cement companies, logistics operators and the Indian Railways.
- In-use: This stage covers users of cement in applications such as manufacture of concrete, fibre cement sheets and boards. The largest demand for cement in FY 2021 was for housing (including low-cost housing), amounting to 68% of total demand. This was followed by infrastructure (22%) and industrial development (10%).[21] A number of cement manufacturers are also involved in manufacturing of concrete and concrete products. Stakeholders identified at this stage include infrastructure companies, concrete manufacturers, fibre cement sheets and boards manufacturers, Ministry of Housing and Urban affairs, Ministry of Road Transport and Highways, the Indian Railways, the Indian Concrete Institute, architects and designers.
- End-of-life: This stage refers to the fate of cement and cement products typically associated with construction and demolition waste from the housing and infrastructure sector, where most cement is used. Stakeholders at this stage include Ministry of Environment and Climate Change, Ministry of Housing and Urban Affairs, CPCB, SPCBs, municipal corporations, infrastructure companies and concrete manufacturers.

Many stakeholders influence more than one life cycle stage; examples include the National Council of Cement and Building Materials, Bureau of Indian Standards, NITI Aayog, Ministry of Finance, Ministry of Science and Technology, Global Cement and Concrete Association, National Academy of Construction (Hyderabad), and industry associations.

[21] IBEF, (2021). Growth of Cement Industry in India – Infographic. Available at: https://www.ibef.org/industry/cement-india/infographic

Chapter 3: Material flow and greenhouse gas emissions across the cement value chain

Part I: Material flow

To establish a baseline for material consumption (raw materials and fuel) across the cement value chain a material flow was developed. This baseline can be used to estimate abatement potential of efficiency measures. Based on an understanding of the cement value chain and data on resource consumption, an economy-wide material flow for the cement sector in 2018-19 was developed. Figure 3 shows the Sankey diagram of the material flow, viewed from left to right. The flow width is proportional to the quantity of the resource represented.

- The left side of the figure represents the consumption of different raw materials (limestone, gypsum and other minor minerals such as bauxite, silica, iron ore, lime sludge and fireclay) and clinker substitutes (such as fly ash and blast furnace slag).
- Imports of limestone, clinker and different types of cement are also represented on the left side of the image.
- The next stage of the image represents the total amount of clinker produced in the country.
- This is followed by the production of cement which takes into account the clinker production, clinker imports, gypsum consumption and consumption of clinker substitutes.
- The total cement produced is then segregated into the following types of cement:
    - Ordinary Portland Cement (OPC)
    - Portland Pozzolana Cement (PPC)
    - Portland Slag Cement (PSC)

      Other cements
- Exports of clinker and different types of cement are shown on the figure's right.
- The total quantity of cement consumed by different sectors is shown at the far right.

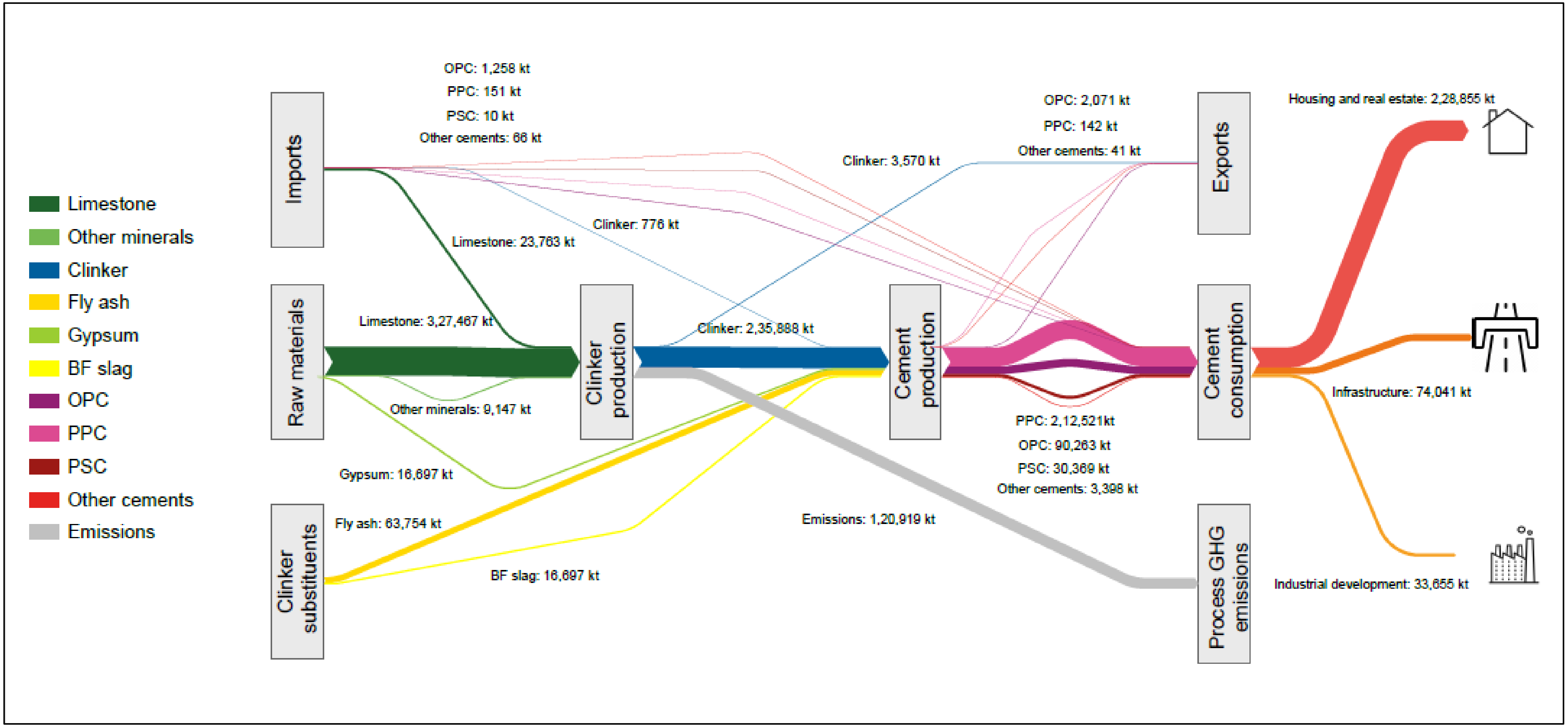

Figure 3: Material flow of cement and associated raw materials in India in 2018-19

In order to develop the material flow, information from all parts of the cement value chain was needed including data on quantities of raw materials consumed in the cement manufacturing process, fuel consumption during manufacturing, the different types of cement and their end uses: sources and some features of the data used to arrive at the flow are described below. The following sub-sections provides details for resource consumption

Raw material consumption

The primary raw material used in the production of cement is limestone. In 2018-19, it is estimated that 3,27,467 kt of limestone was consumed for the production of cement, accounting for 94% of the total limestone demand in the country.

In the case of blended cements, clinker substitutes are additional raw materials. In 2018-19, 63,754 kt of fly ash was consumed in the production of PPC and 16,697 kt of blast furnace slag was consumed in the production of PSC.[22]

Data on the use of limestone and the following minor raw materials for cement production were collected from the annual Indian Minerals Yearbook published by the Indian Bureau of Mines.

- Bauxite
- Silica (quartz, silica sand and quartzite)
- Iron ore
- Lime sludge
- Fireclay
- Kaolin (China Clay)
- Ochre
  Other calcareous minerals

For the purpose of this study, these have been clubbed together as 'Other minerals' as the quantity of consumption is very low in comparison to limestone consumption. Table 2 below summarizes total raw material consumption for cement manufacturing in 2018-19.

Table 2: Raw material consumption for cement production in 2018-19[23]

Raw material	Quantity consumed (in kt)
Limestone	3,27,467
Fly ash	63,754
Blast furnace slag	16,697
Bauxite	2,214
Silica*	780
Iron ore	1,080
Lime sludge*	413
Fireclay*	435

[22] Calculation of fly ash and BF slag consumption based on clinker-to-cement ratio. For detailed calculations, refer to section titled 'Clinker-to-cement ratio' (Page 19).

[23] Limestone, bauxite, iron ore and ochre: Indian Bureau of Mines (2022). Indian Minerals Yearbook 2020 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=1588
Silica, lime sludge, fireclay, kaolin and other calcareous minerals: Indian Bureau of Mines (2018). Indian Minerals Yearbook 2016 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=882

Kaolin (China clay)*	1,052
Ochre	1,456
Other calcareous minerals*	1,717

*Indian Bureau of Mines reclassified these minerals as 'Minor Minerals' in 2015. Production data are not available after this reclassification. The last available data (2015-16) have been used instead.

Fuel consumption

Fuel is consumed at two points during cement production

1. directly in kilns to generate heat, and
2. in captive power plants (CPP) to generate electricity.

Coal, lignite and petcoke are used to fuel cement kilns while coal is normally uses in captive power plants. However, coal use by the cement industry has been declining over the years, with many companies using petcoke instead which has a higher calorific value. Plants across the country have also begun using alternative fuels such as biomass, tire chips, refuse-derived fuel (RDF), CPP bed ash and dolochar.[24] Fuel consumption for cement production between 2002-03 and 2017-18 is shown in Figure 4.

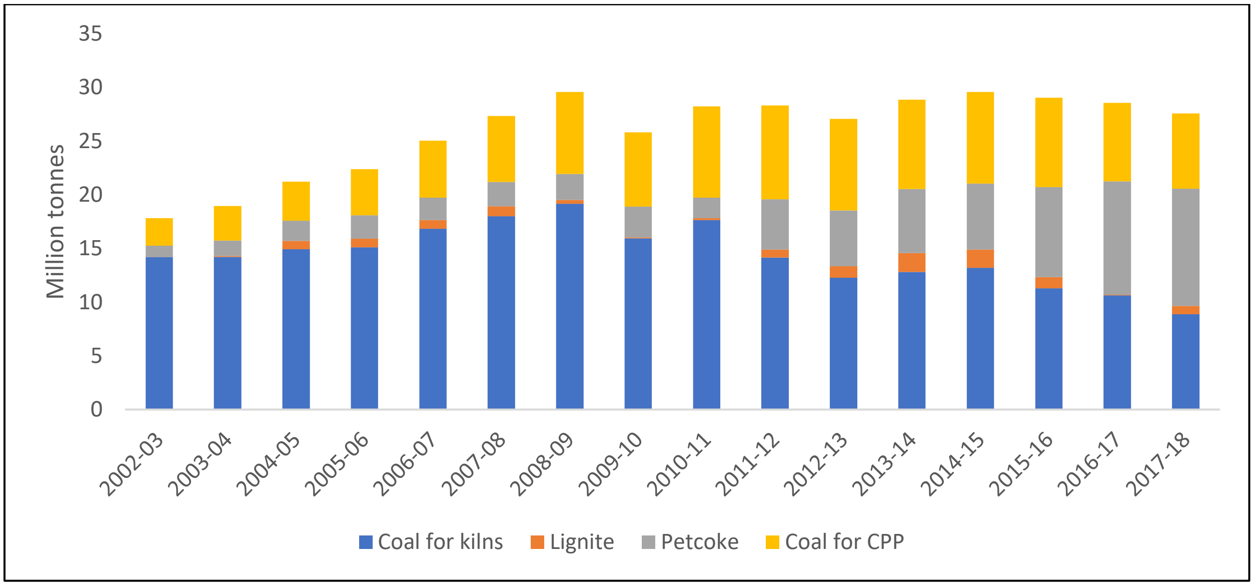

Figure 4: Fuel consumption for cement manufacturing between 2002-03 and 2017-18

Cement mix

The country's cement mix has been gradually changing: the share of blended cement (PPC and PSC) has increased from 54% in 2003-04 to 72% in 2018-19, while the share of OPC decreased from nearly half (46%) to one-fourth (27%) in the same duration (Table 3). The rising use of blended cements can be attributed to increased awareness of the GHG emission reduction potential of blended cements and the increased availability of fly ash and blast furnace slag for use in cement production. In 2018-19, 27% of

[24] Dolochar is an industrial solid waste produced as a by-product of direct reduction of iron (DRI) process for the production of sponge iron.

the fly ash generated in the country was used in cement production.[25] Cement production also consumes nearly all the granulated blast furnace slag generated in the country.[26]

Table 3: Cement mix in India between 2003-04 and 2018-19[27]

	OPC	PPC	PSC	Others
2002-03	50%	39%	10%	1%
2003-04	46%	44%	10%	1%
2004-05	44%	47%	8%	0%
2005-06	39%	52%	8%	0%
2006-07	31%	60%	8%	0%
2007-08	25%	66%	8%	0%
2008-09	25%	66%	8%	0%
2009-10	31%	61%	7%	1%
2010-11	31%	61%	7%	1%
2011-12	31%	61%	7%	1%
2012-13	31%	61%	7%	1%
2013-14	31%	61%	7%	1%
2014-15	31%	61%	7%	1%
2015-16	31%	61%	7%	1%
2016-17	27%	65%	8%	0%
2017-18	27%	63%	9%	1%
2018-19	27%	63%	9%	1%

Based on the national cement mix in 2018, the production of different types of cements was estimated for 2018-19 (Table 4).

Table 4: Cement mix in 2018-19

Type	Percentage	Quantity (kt)
OPC	27%	91,076
PPC	63%	2,12,512
PSC	9%	30,359
Others	1%	3,373
Total	**100%**	**3,37,320**

Clinker-to-cement ratio

The clinker-to-cement ratio represents the percentage of clinker in cement. This was required to estimate quantity of clinker and its substitutes consumed for cement manufacturing. As clinker production is an emission intensive process, substitution of clinker results in reduced emissions. A lower clinker-to-cement ratio translates into larger emissions reductions.

[25] Central Electricity Authority (2020). Report on Fly Ash Generation and its utilization at coal/lignite based Thermal Power Stations in the country for the year 2018-19. Available at https://cea.nic.in/old/reports/others/thermal/tcd/flyash_201819.pdf

[26] Indian Bureau of Mines (2018). Indian Minerals Yearbook 2017 (Part- II: METALS AND ALLOYS) – Slag – Iron and Steel. Available at: https://ibm.gov.in/writereaddata/files/12142018183814Slagironandsteel%202017.pdf

[27] Cement mix data obtained from various sources. Refer to Annex 4.2 for detailed sources.

The clinker-to-cement ratio of OPC, PPC and PSC produced in India between 2010-11 and 2018-19 is presented in Table 5. While the ratio has remained nearly constant for both OPC and PPC, there has been a significant decrease in the ratio for PSC.

Table 5: Clinker-to-cement ratio between 2010-11 and 2018-19[28]

	OPC	PPC	PSC
2010-11	0.95	0.68	0.55
2011-12	0.95	0.70	0.40
2012-13	0.95	0.69	0.41
2013-14	0.94	0.68	0.42
2014-15	0.94	0.67	0.44
2015-16	0.94	0.66	0.45
2016-17	0.94	0.66	0.43
2017-18	0.94	0.65	0.40
2018-19	0.94	0.65	0.40

The 2018-19 values for clinker-to-cement ration were used to estimate the consumption of clinker, gypsum, fly ash and blast furnace slag for the production of OPC, PPC and PSC. It has been assumed that 5% gypsum is used in all three types of cement. Table 6 below presents the estimates for consumption of clinker, gypsum, fly ash and blast furnace slag.

Table 6: Consumption of clinker, gypsum, fly ash and blast furnace slag in 2018-19

Type of cement	Clinker quantity (kt)	Gypsum quantity (kt)	Fly ash quantity (kt)	BF slag quantity (kt)
OPC	85,611	4,554	NA	NA
PPC	1,38,133	10,626	63,754	NA
PSC	12,144	1,518	NA	16,697

Import and export

Trade data for cement and limestone was based on the relevant Indian Trade Clarification (ITC) Harmonized System (HS) code (details in Annex 1). These codes were used to collect the trade data for the years 1996-97 to 2019-20 from the Ministry of Commerce and Industry database.[29]

Import and export data were collected for the following:

- Limestone
- Clinker
- OPC
- PPC
- PSC

[28] Clinker-to-cement ratio data obtained from various sources. Refer to Annex 4.3 for detailed sources.
[29] Ministry of Commerce and Industry database. (n.d.). *Export Import Data Bank Version 7.1 – Tradestat*. Available at https://tradestat.commerce.gov.in/eidb/default.asp

- Other cement

Trade data for 2018-19 are presented in Table 7.

Table 7: Import and export of limestone, clinker and the different types of cement in 2018-19 (in kt)

Commodity	Import	Export
Limestone	23,763	3,855
Clinker	776	3,570
OPC	1,258	2,071
PPC	151	142
PSC	10	0.00
Other cement	66	41

Based on the data collected, it is clear that the Indian cement industry is very localized and self-sufficient. In comparison to the total domestic production and consumption of cement, imports and exports are negligible.

It is unclear what percentage of the limestone imported into the country is used for the production of cement as the HS code considered (252100) includes data for limestone used for both lime and cement production. Assuming that the entire limestone imported in 2018-19 was used for cement production, imports contributed to only 7.25% of the total limestone consumed for cement production. However, in reality this figure could be lower.

The cement industry also imports coal for use in kilns and CPPs. The percentage share of imported coal in the industry's coal consumption has been increasing steadily, from only 22% in 2002-03, to 47% in 2018-19.

The estimation of consumption of the different types of cement was based on the production and trade data (description in Annex 2). The data for 2018-19 is presented in Table 8.

Table 8: Production, import, export and consumption of cement in 2018-19 (in kt)

Type	Production	Import	Export	Consumption
OPC	91,076	1,258	2,071	90,263
PPC	2,12,512	151	142	2,12,521
PSC	30,359	10	0.00	30,369
Others	3,373	66	41	3,398

Sector-wise consumption

Cement consumption in India increased at a rate of 6.5% per annum between 2006-07 and 2018-19, with the housing and real estate sector being the largest consumers, followed by infrastructure development and industrial development. Although the per capita consumption of cement in India (195 kg) is significantly lower than the world average (500 kg)[30], the consumption is expected to rise because of a government focus on housing and infrastructure projects.

[30] Indian Bureau of Mines (2021). Indian Minerals Yearbook 2020 (Part- III: MINERAL REVIEWS) - Cement. Available at: https://ibm.gov.in/writereaddata/files/12102021174214Cement_2020.pdf

The percentage share of cement demand by sector in FY20 was used to calculate the sector-wise consumption of cement in India in 2018-19.

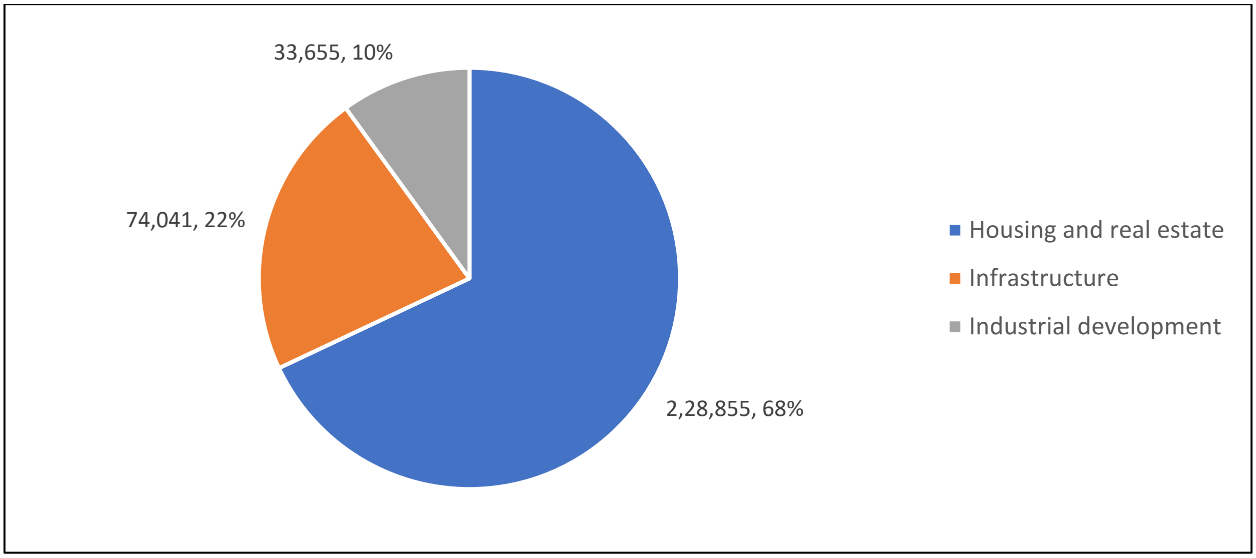

Figure 5: Sectoral consumption of cement in 2018-19 (in kt)

End-of-life

The primary use of cement is as a binding material in concrete – upon contact with water, it hardens and adheres to other materials such as sand and aggregates, binding them together. Because of its binding properties, it is difficult to recover cement from concrete at the end of its life: as a consequence, most cement is disposed as construction and demolition (C&D) waste.

Part II: Greenhouse gas emissions

The greenhouse gas emission baseline for the cement value chain was developed by estimating CO_2 equivalent emissions across different life cycle stages. The baseline can be used in future studies to measure abatement potential for resource efficiency and circular economy measures that have been identified in Chapter 4.

Table 9: Summary of life cycle stage and emissions considered in this study

	Life cycle stage		**Emissions included**
1	Extraction	Limestone mining	• use of explosives for blasting and usage of high-speed diesel in machinery • transport within mines
		Coal and lignite mining	• use of lubricant, high speed diesel and electricity • transport within the mine *excludes emissions from mining of petcoke
2	Cement production		• clinker manufacturing (calcination) • fuel (coal, lignite and petcoke) consumption in kilns and for electricity • transport within cement plants
3	Transport		• transport of cement by rail and road *excludes emissions from • transport of raw material • transport of cement by waterways/sea
4	In-use		There are no emissions at this stage. Recent studies suggest sequestration taking place due to carbonation during the service life of concrete structures, but approval by the IPCC is pending. An estimate for sequestration has been prepared, but not included in overall calculations.

The general formula used to calculate emissions was:

$$\textit{GHG emissions} = \textit{Activity data} \times \textit{Emission factor (EF)}$$

Activity data refers to the amount of resource consumed, and emission factor refers to the average emission rate of a given greenhouse gas relative to the consumption of a given resource. While greenhouse gas accounting exercises refer to emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), emissions of carbon dioxide in the cement value chain are significantly larger than those of methane or nitrous oxide and therefore it is the only GHG being considered here. The methodology for emission calculations is described in Annex 3.

Figure 6 shows the CO_2 equivalent emissions from each life cycle stage between 2010-11 and 2018-19. Emissions from the cement value chain have grown at 4.4% from 154 million tonnes CO_2 eq to 217 million tonnes CO_2 eq. The largest share of emissions is at the manufacturing stage (due to clinker production and energy generation). Recent studies suggest that sequestration of CO_2 occurs during the in-use stage of concrete; however, in the absence of an approved method to incorporate this sequestration has not be factored into the calculations.

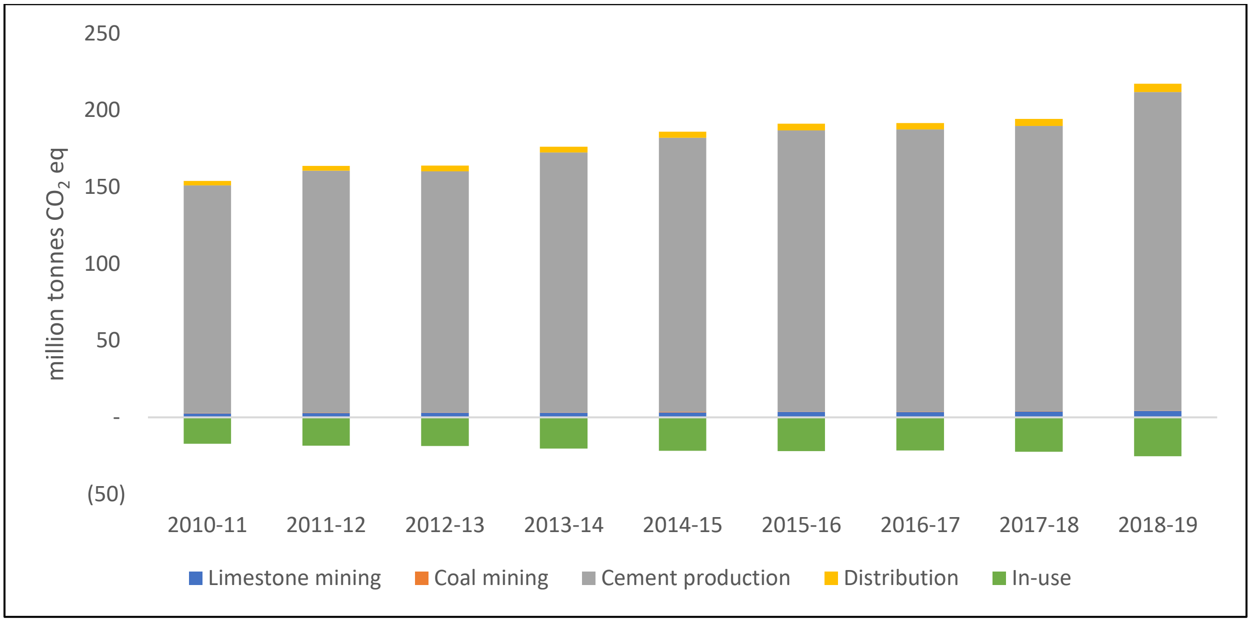

Figure 6: CO_2 eq emissions at different life cycle stages of the cement value chain between 2010-11 and 2018-19

Extraction

Emissions associated with extraction of limestone, coal and lignite for use in cement production were estimated. On average, the emissions at this stage form only 2% of total emissions in the cement value chain. Overall, there are no observable trends in emissions at the extraction stage.

Limestone mining

Limestone is extracted in open-cast mines with GHG emissions occurring from the use of explosives for blasting, use of diesel in machinery and transport within the mines. Emissions from limestone mining for consumption in cement production have risen at a rate of 7% annually from 2010-11, reaching 4.34 million tonnes CO_2 eq in 2018-19.

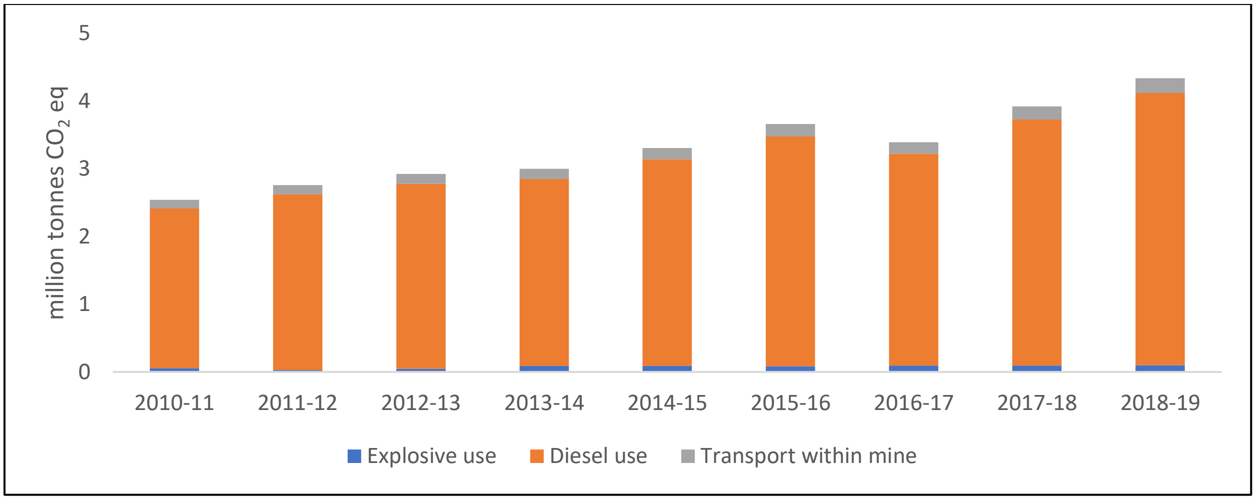

Figure 7: Emissions from limestone mining for use in cement production between 2010-11 and 2018-19

Coal and lignite mining

Emissions from coal and lignite mining were estimated using the methodology followed by GHG Platform India. During mining, emissions are associated with the use of lubricants, high-speed diesel, power consumption and transport within mines. The Indian cement industry's shift to petcoke is reflected by declining emissions from coal and lignite mining, at a rate of 6% annually from 2010-11. In 2018-19, emissions from coal and lignite mining for consumption during cement production reached 0.19 million tonnes CO_2 eq.

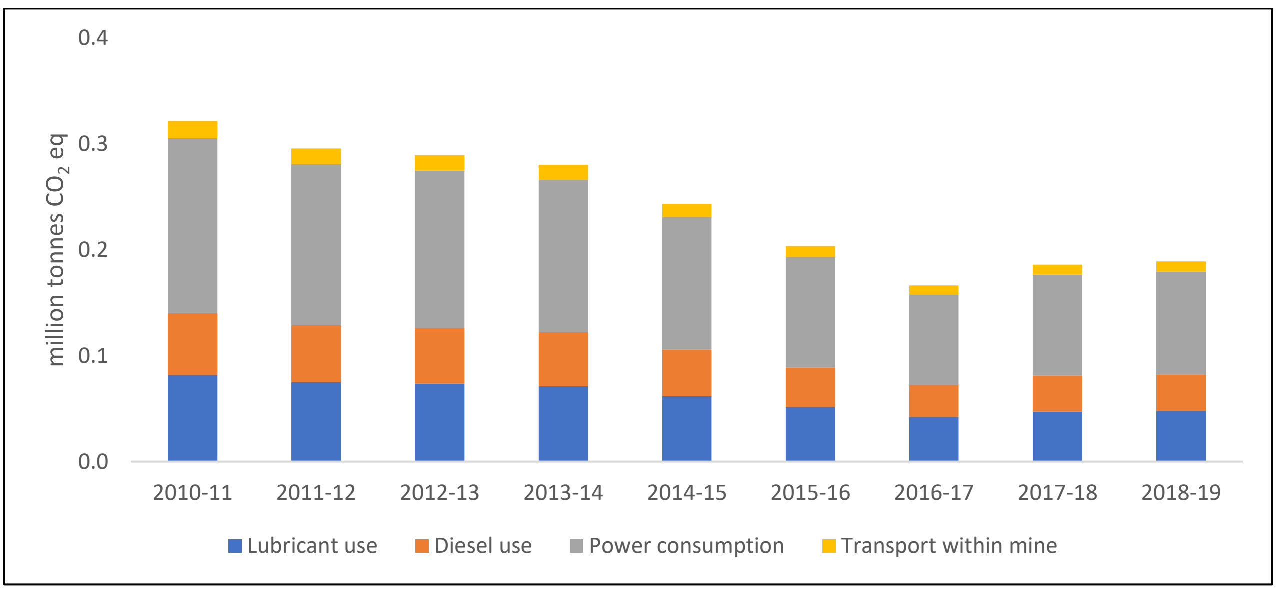

Figure 8: Emissions from coal and lignite mining for use in cement production between 2010-11 and 2018-19

Cement production

Cement production is an emissions-intensive process, primarily due to the calcination of limestone: clinker production accounts for an average of 60% of the total emissions at the manufacturing stage. The rest of the emissions are from fuel used in kilns and electricity consumption (35%) and transport within the plants (5%).

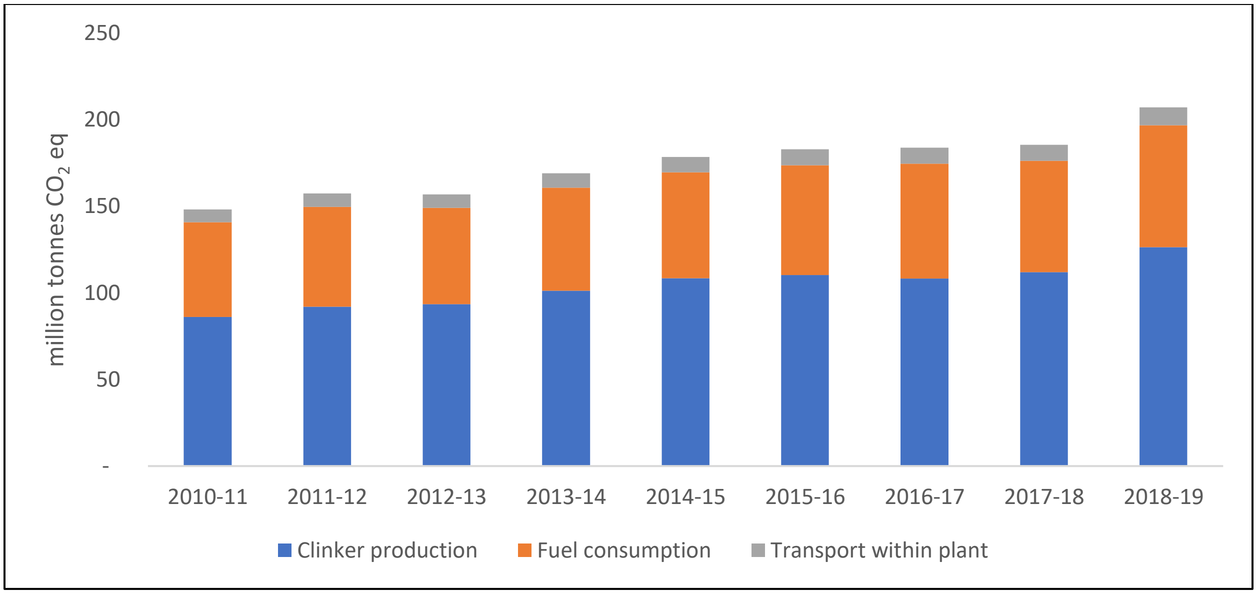

Figure 9: Emissions from cement production between 2010-11 and 2018-19

On the whole, emissions at the manufacturing stage have been rising at a rate of 4% annually from 2010-11, reaching 207 million tonnes CO_2 eq in 2018-19. Of this, 126 million tonnes were from the calcination process, 70 million tonnes were from fuel consumption and the remaining 10 million tonnes were from transport within the plants. It is notable that emissions from fuel consumption are growing at a slower rate annually (3%) than those from clinker production (5%) and internal transport (4%). Figure 10 shows the relative share of these different activities in the emissions for 2018-19.

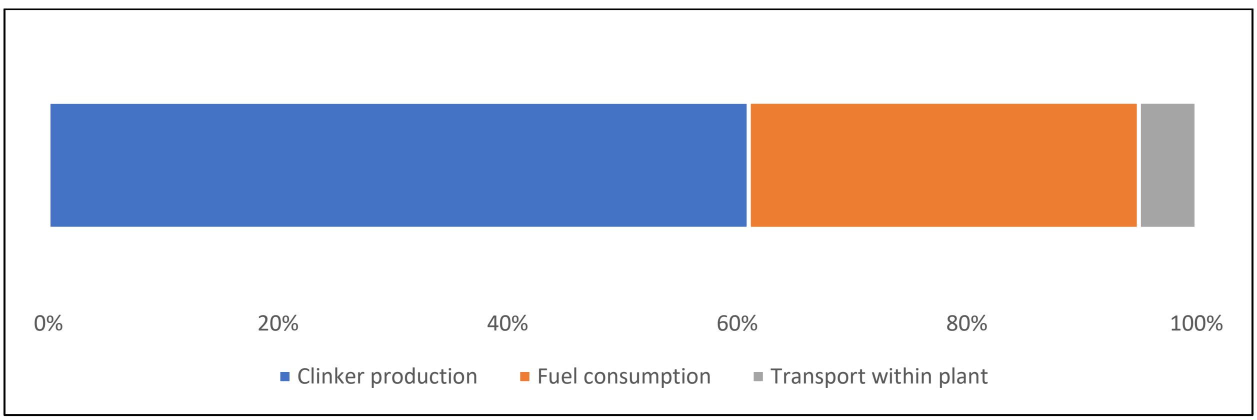

Figure 10: Percentage share of emissions from clinker production, fuel consumption and internal transport from cement production in 2018-19

There has been a significant change in the contribution of different fuels to the fuel emissions between 2010-11 and 2018-19. Coal, which is used in both kilns and in CPPs, contributed nearly 88% to the fuel emissions in 2010-11 but this has reduced to 41% in 2018-19. Emissions from petcoke have risen from 11% in 2010-11, to 57% in 2018-19. As mentioned earlier, this is because of the cement industry's gradual shift to petcoke due to its higher calorific value. Figure 11 shows the percentage share of emissions from coal, lignite and petcoke use between 2010-11 and 2018-19.

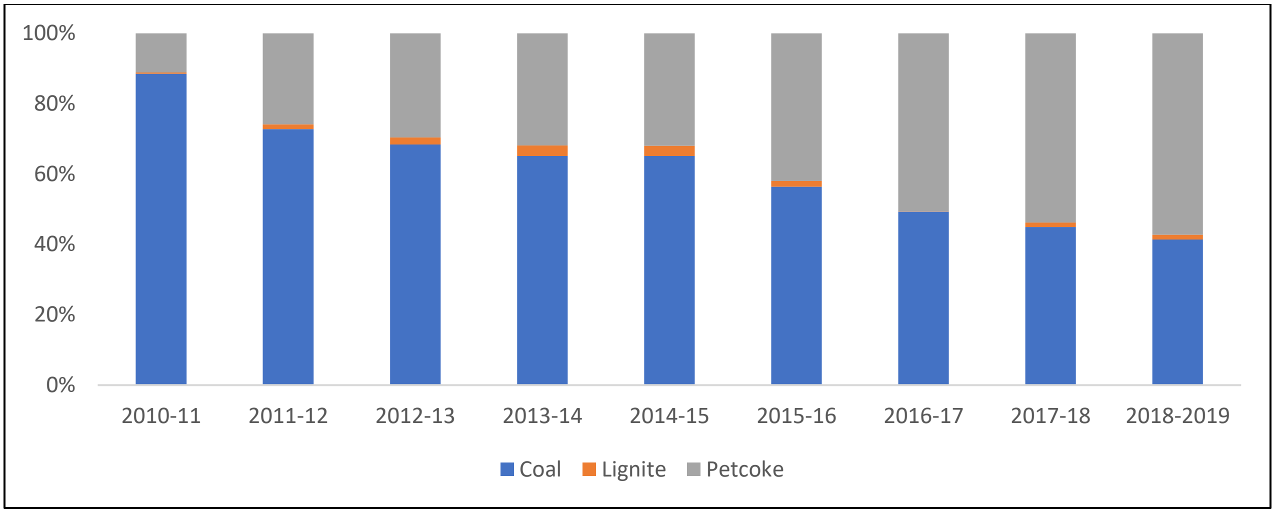

Figure 11: Percentage share of emissions from use of coal, lignite and petcoke between 2010-11 and 2018-19

Distribution

In India, cement is distributed by rail, road and sea but emissions have been calculated for distribution of cement by road and rail only, in this study. Emissions from distribution of cement by sea were not estimated because data are not available and also because little cement is transported by sea.

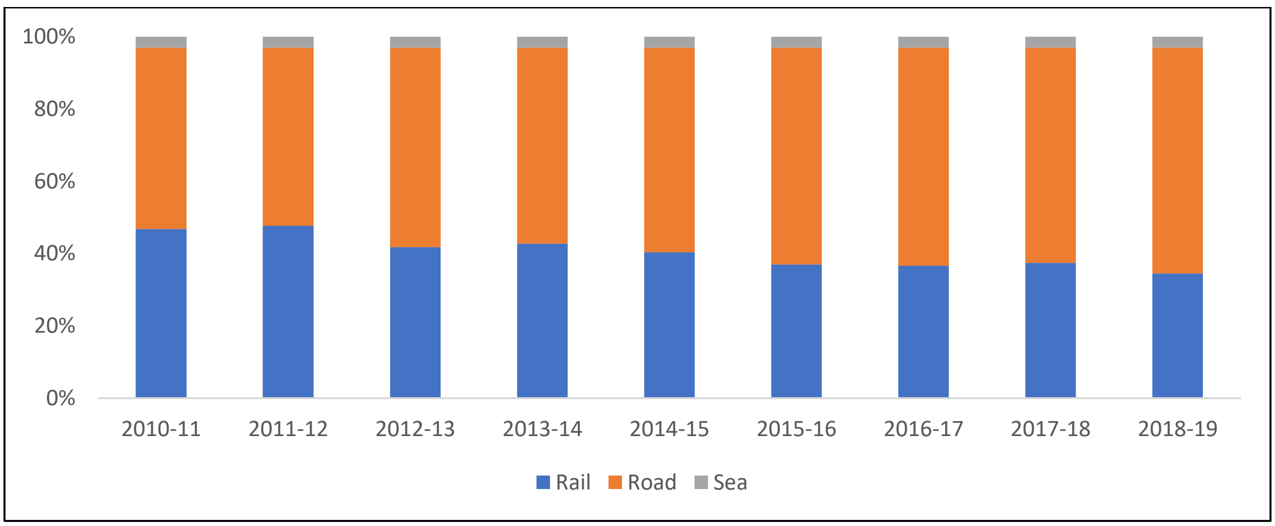

Figure 12: Percentage share of different modes of transport for cement distribution between 2010-11 and 2018-19

Emissions due to distribution of cement have risen at a rate of 8% annually from 2010-11, reaching 5.34 million tonnes CO_2 eq in 2018-19. The rising emissions can be attributed to a rise in the percentage share of road transport which is more emission-intensive compared to rail transport. While 62% of the total cement produced is distributed by road, 87% of emissions from distribution were attributed to road transport in 2018-19. 35% of cement produced is distributed by rail, but rail transport accounts for only 13% of the emissions. Figure 13 shows the emissions from each of the two modes of transport between 2010-11 and 2018-19.

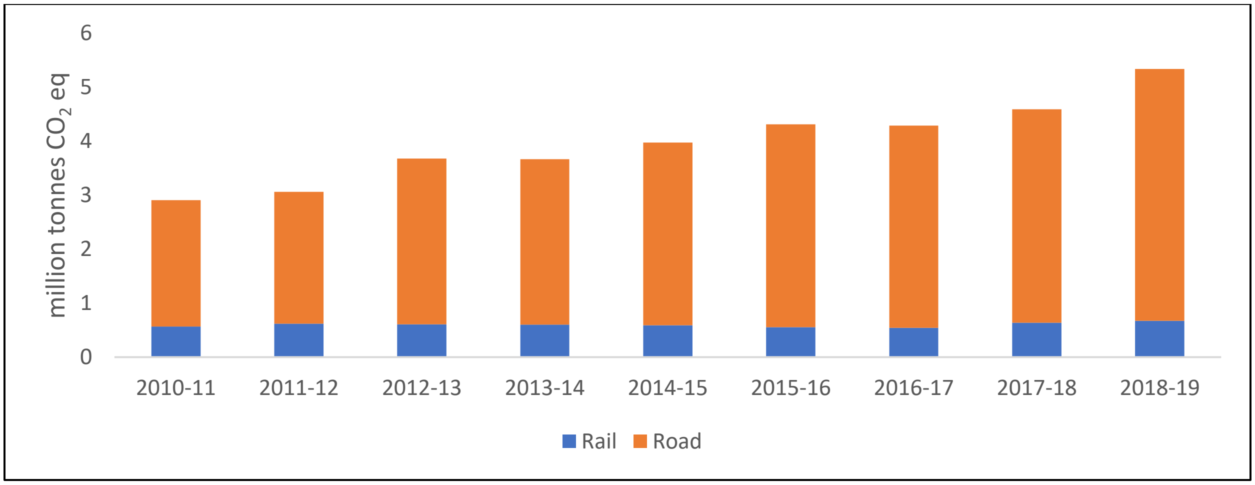

Figure 13: CO_2 emissions from distribution of cement by rail and road between 2010-11 and 2018-19

In-use

Recent studies have indicated that there is potential for GHG sequestration at the in-use stage. This occurs through a process called carbonation in which CO_2 in the air reacts with hydrated cement phases in concrete structures to form $CaCO_3$. Carbonation occurs over the service life of concrete structures as also during its demolition and subsequent reuse as secondary product (for instance, when concrete is recycled to be used as aggregates).

In principle, carbonation should be able to sequester all the CO_2 that was emitted during clinker production (calcination emissions). However, the rate of carbonation in reality is dependent on several factors including, but not limited to

- exposed surface area
- porosity
- water/cement ratio
- presence of alternate raw materials such as fly ash and blast furnace slag
- presence of surface coatings

Reabsorption of atmospheric CO_2 through carbonation is not accounted for in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This can result in reduced accuracy in national emission estimates. These guidelines have highlighted that further research is required before including it in national inventories.

Since then, several studies have been carried out to understand the rate of carbonation and prepare models for CO_2 uptake. Based on existing research, the IVL Swedish Environmental Research Institute has developed methods and models for the calculation of CO_2 uptake in concrete to be presented to IPCC for inclusion in the Guidelines for National Greenhouse Gas Inventories.[31]

[31] Stripple, H.; Ljungkrantz, C.; Gustafsson, T.; Andersson, R. *CO_2 Uptake in Cement-Containing Products. Background and Calculation Models for IPCC Implementation*, 1st ed.; Report number: B 2309; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2018. Available at: https://www.ivl.se/english/ivl/publications/publications/co2-uptake-in-cement-containing-products---background-and-calculation-models-for-ipcc-implementation.html

The annual uptake of CO_2 was estimated using the Tier 1 method recommended by the IVL study. Annually, 20% of the emissions at the calcination stage are reabsorbed due to carbonation during the service life of concrete structures. In 2018-19, 25 million tonnes of CO_2 were sequestered by concrete structures during their service life. Figure 14 shows the amount of CO_2 sequestered through carbonation between 2010-11 and 2018-19. While this report has estimated sequestered carbon dioxide, it has not been included in the overall calculations, pending approval by the IPCC.

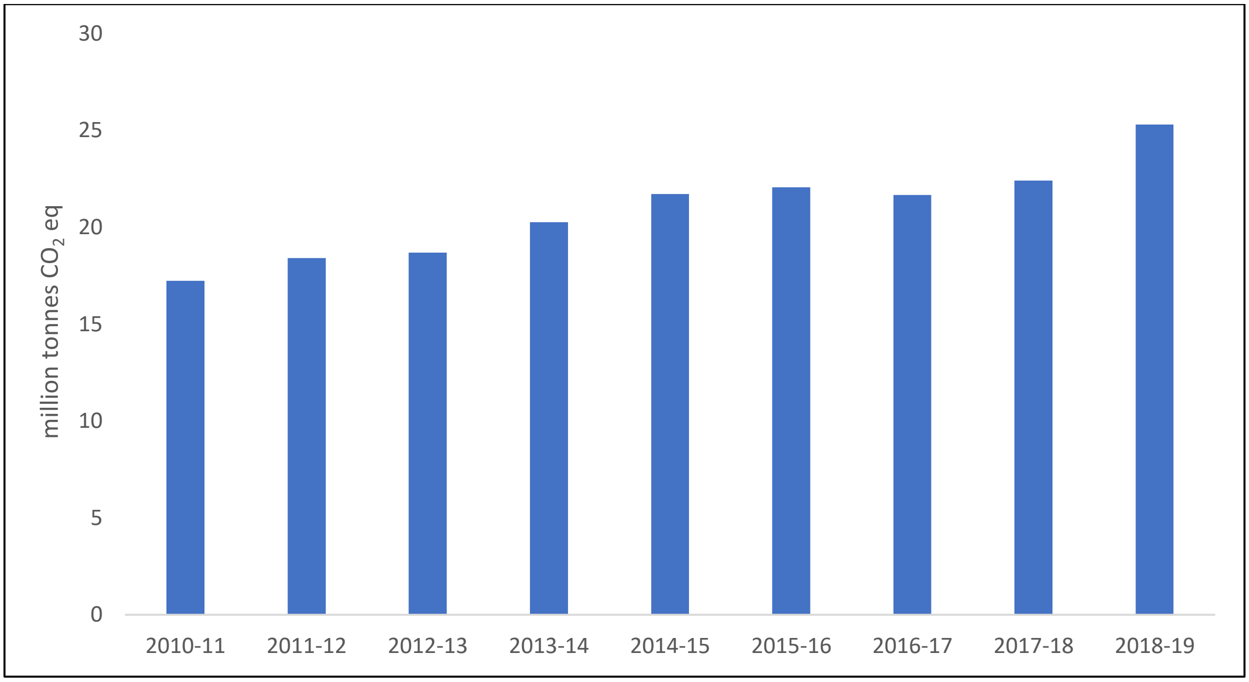

Figure 14: Annual CO_2 uptake due to carbonation during the in-use stage between 2010-11 and 2018-19

End-of-life

Carbonation also occurs during demolition of concrete structures and their subsequent reuse as secondary products (such as recycled aggregates). However, the CO_2 uptake from this stage has not been estimated as comprehensive data on C&D waste and quantity of recycled concrete is not available in India.

Chapter 4: Efficiency measures across the cement value chain

It is apparent from the material flow and the emission estimates that the cement value chain is both resource-intensive, and emissions-intensive (Figure 3 and 6): this suggests that measures to reduce GHG emissions need to be examined at each life cycle stage, and not only during manufacture. A review of literature was carried out to identify such interventions.

Some of the interventions identified have been commercialized in other countries but need to be explored in the Indian context. Some measures recommend addition of new substances such as admixtures, which, if adopted in India, would require current standards to be modified.

Manufacturing

Several technologies to reduce emissions during manufacture are in use by the cement industry, and their success is evident from the fact that the Indian cement industry is the most energy efficient globally.[32] Some of these energy efficiency interventions are:

- Use of alternative raw materials and fuels
- Use of modern burners to reduce emissions
- Fossil fuel switching from coal to low carbon fuels
- Use of captive power plants
- Installation of waste heat recovery systems
- Use of efficient coolers and dry kilns
- Automation, optimization and process control
- Use of pre-heater and kiln systems
- Use of separators, variable speed or frequency drives, auxiliary equipment
- Grinding of raw materials separately

Waste heat recovery systems have the potential to reduce GHG emissions significantly and are used extensively in the Indian context: opportunities to improve their performance were identified in a separate study and presented in detail in Addendum 2.

Green hydrogen could replace coal in cement manufacturing while Carbon capture storage and use is another mitigation technology, still being developed: given the potential for growth in this area, a summary of carbon-capture technologies and their adoption at different locations worldwide has been included at Annex.

There are other technologies for abatement of emissions from energy use which have not been commercialized. For instance, the use of mineralizers to improve burnability of the raw mix, fluidized-bed advanced cement kiln systems (FAKS) and oxygen enrichment.

At the manufacturing stage, clinker production is associated with the largest emission of GHGs, followed by fossil fuel combustion for energy. The efficiency technologies listed above focus mainly on reducing emissions from fossil fuel combustion. Material efficiency technologies listed below focus on reducing

[32] AEEE, (2020). Reducing Cement Sector Emissions: Approaches to reduce the demand of Cement from Construction. Available at: https://aeee.in/wp-content/uploads/2020/12/cement-sector-emission.pdf

emissions at the clinker production stage. Some material efficiency strategies identified at the manufacturing stage, which are at different stages of commercialization are listed below:

- Use of alternative clinkers (at the calcination stage to reduce limestone requirement) such as
  - Belite-rich portland cement clinkers: The quantity of belite is more in belite rich Portland clinker as compared to traditional OPC. The quantity of limestone in the clinker raw material mix is also reduced. These can be manufactured in the same way as OPC clinkers, but they require a low clinkering temperature, which on an average is 100^{o}C lower than OPC. Low temperature allows the usage of low-grade kiln fuels, which reduces the specific kiln requirement and CO_2 emissions by 10% as compared to OPC. Belite-rich portland cement clinkers have been in commercial use in China for the last 15 years.[33]
  - Calcium sulfoaluminate (CSA) cements: In CSA cements the quantity of limestone is reduced and aluminum based raw materials such as ye'elimite and belite are increased in the clinker raw material mix. These cements can be manufactured in conventional Portland cement plants and reduce emissions by 20% to 30% as compared to OPC. They are commercially used in China.[34]
  - Belite-Ye'elimite-Ferrite (BYF) clinkers: Belite, ye'elimite and tetracalcium alumino-ferrite (C4AF) are added to the clinker mix. This clinker raw material mix requires 20% to 30% less limestone, but a higher quantity of aluminum-rich raw materials (such as bauxites, clays, coal combustion ashes and municipal waste incinerator ashes.). As described in Chapter 3, calcination of limestone is an emissions-intensive process, and reduction in the quantity of limestone used will reduce emissions.[35]
  - Magnesium-based cement: magnesium silicates are used in place of limestone as primary raw material. The technology is yet to be scaled.[36]
- Clinker substitution: At the grinding stage, volume of clinker is reduced by using industrial byproducts/waste as clinker substitutes. Commonly used substitutes are blast furnace slag for PSC and fly ash for PPC. These cements are already widely used in India, and their share in total cement produced in the country is rising. Other clinker substitutes available are:
  - Calcined clay: Portland cement clinker can be substituted with calcined clays at a substitution rate of 30%. When clay is calcined at high temperatures of around 600^{o}C they act as highly reactive supplementary cementitious materials (SCMs). Clays which contain kaolinite can also produce reactive materials when calcined at higher temperatures (600 to 850^{o}C).[37]
  - Fillers: Portland cement clinker can also be substituted with fillers, as they are inert or inactive. Fillers are produced by grinding suitable minerals into fine particulate material. They do not require calcining, and the only energy requirement is for grinding. A variety of minerals such as sandstone, quartz, dolomite and granite can be used as fillers, but

[33] Refer to Annex 4.4 for detailed sources.
[34] Refer to Annex 4.5 for detailed sources.
[35] Refer to Annex 4.6 for detailed sources.
[36] Refer to Annex 4.7 for detailed sources.
[37] Refer to Annex 4.8 for detailed sources.

the most commonly used filler is limestone. Fillers are widely used as clinker substitute.[38]

    - Fine limestone: Portland cement clinker is substituted with fine limestone. Fine limestone can be used directly as SCM without heating it to a high temperature to produce clinker. Because of the relatively low temperature, decarbonization does not occur. At the low substitution rate of 10% to 15% fine limestone is considered a filler and not a supplementary cementitious material.[39]
    - Combinations:
        - Calcined clay and fine limestone: Portland cement clinker is substituted with a combination of calcined clay and fine limestone. It produces a cement known as limestone calcined clay cement or 'LC3', which will perform well even at high substitution rate of clinker (up to 50%). The pilots have been successful in India, but approvals by Bureau of Indian Standards (BIS) are awaited for commercialization of this cement.[40]
        - Fly ash and granulated slag: Portland cement clinker is substituted with the combination of both fly ash and granulated slag, and these cements are called composite cement. The following proportion of substitution is suggested by the Bureau of Indian Standards: Portland cement clinker/OPC can be present within the range of 35% to 50%. This cement is commercially manufactured by many cement plants in India.[41]
    - Other blending materials: Portland cement clinker is substituted with other blending materials from non-ferrous industries or mineral processing industries such as lead zinc slag, copper slag, kimberlite and marble slurry.[42]
- Alternative cements such as: Alkali-activated cements/ Geopolymer cements: These are an alternative to ordinary Portland cement and are formed by a reaction between an alkali activator such as sodium silicate and an aluminosilicate precursor such as fly ash, which leads to the polymerization of aluminate and silicate. The production of this cement is commercialized in following countries: Australia, Brazil, Canada, China, Czech Republic, India, Netherlands, Russia, South Africa, Ukraine, United Kingdom, United States.[43]

Distribution

Rail is used to transport bulk raw materials such as coal and limestone, heavy duty trucks are used to distribute cement from the manufacturing sites to retailers and distributors. Transport is an important part within each lifecycle stage, as well: for instance, at the manufacturing stage transport accounts for

[38] Refer to Annex 4.9 for detailed sources.
[39] Refer to Annex 4.10 for detailed sources.
[40] Refer to Annex 4.11 for detailed sources.
[41] WBCSD, (2018). Low Carbon Technology Roadmap for the Indian Cement Sector: Status Review 2018. Available at: https://docs.wbcsd.org/2018/11/WBCSD_CSI_India_Review.pdf
[42] IEA and WBCSD, (2013). Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry. Available at: https://docs.wbcsd.org/2013/02/Low_Carbon_Technology_for_the_Indian_Cement_Industry_IEA_WBCSD_Feb_2013.pdf
[43] Refer to Annex 4.12 for detailed sources.

5% of GHG emissions.[44] Given that the demand for cement is growing it is clear that emissions due to transport and distribution will increase proportionately. Road transport, which accounted for about 60% of total cement distribution in 2018-19, is identified as a hard-to-abate sector (heavy-duty road transport).[45] In 2018-19, road transport accounted for 96% of total transport emissions (distribution as well as internal transport at each lifecycle stage): these data indicate the potential for improvements in transport in relation to the cement sector.

Some of the interventions identified here can be generalized to all transport/logistics operations, but if they are closely examined and implemented strictly in the cement sector, large benefits in terms of emissions reductions could result. Implementing these measures will require cement manufacturers to prioritize efficiency of transport by paying attention to aspects such as modes of transport used for distribution of finished products. Some interventions identified are listed below:

- *Mode of transport*: Wherever possible prefer transport by shipping followed by rail, road and air. Globally, the shift from road to railways and shipping, and from short-haul aviation to high-speed rail might reduce emissions by 20%. In India however, the shift has been occurring in the opposite direction. Distribution of cement from manufacturing plants to end-users has been gradually shifting from rail to road. While 62% of the total cement produced is distributed by road, 87% of emissions from distribution were attributed to road transport in 2018-19. 35% of cement produced is distributed by rail, but account for only 13% of the emissions. It is crucial to choose rail over road wherever possible to reduce emissions. Shipping must also be considered wherever possible – it is more efficient terms of costs during transportation, and in the long-term with respect to aspects such as health impacts due to air pollution abatement.[46]
- *Use of dedicated freight corridors for transport of raw materials*: The Indian Railways is setting up dedicated freight corridors to reduce the pressure from existing railway networks and allow industries to transport raw materials via rail networks which are less carbon intensive.[47]
- *Optimizing network logistics* such as network's nodal points, inter-related transport flows, distribution hierarchy, will result in both energy and cost savings.[48]
- *Adoption of new fuel technologies* such as biodiesels, liquified natural gas, e-methanol, e-ammonia. Electric batteries, hydrogen fuel cells, hybrids of battery and fuel cells need to be explored for large-scale adoption in the cement value chain. CNG trucks can be competitive in the near-term while, both battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs) should be considered in the longer term. BEVs can be competitive where distances are less than 500 km and FCEVs trucks can be preferred for transport distances beyond 500 km.

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[44] WWF, (2008). A blueprint for a climate friendly cement industry. Available at: https://wwfint.awsassets.panda.org/downloads/english_report_lr_pdf.pdf

[45] ETC, (2018). Mission possible: Reaching net zero carbon emissions from harder-to-abate sectors by mid-century. Available at: https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC_MissionPossible_FullReport.pdf

[46] Refer to Annex 4.13 for detailed sources.

[47] Ernst & young, (2011). Green House Gas Emission Reduction Analysis for Dedicated Freight Corridor. Available at: https://documents1.worldbank.org/curated/en/688251468035380566/pdf/E47320V30P150100Box385425B00PUBLIC0.pdf

[48] Refer to Annex 4.14 for detailed sources.

Some cement manufacturing companies have made commitments to transition their fleets to electric vehicles (EV) by joining the EV100 initiative.[49]

Cement manufacturers can lead the transformation of the freight transport sector by demanding more efficient fleets from suppliers of transport services.

In-use

Managing the use of cement at this stage can help reduce the overall demand for cement and hence the emissions associated with extraction of raw materials, production and transport. Following measures have been identified:

- *Use of fillers*: Fillers are finely divided minerals, which used in combination with dispersant admixtures can be used to replace up to 60% of cement in concrete. These do not require calcination. However, the high cost of admixtures and standards for minimum requirement of cement in concrete can limit their use. Use of fillers has been found feasible in Germany and Brazil in precast and ready-mix concrete.[50]
- *Reducing cement demand through industrialized production and pre-fabrication*: Increasing the industrialized production of cement and cement-based materials by using dry-mix mortar, ready-mix concrete and pre-cast concrete compounds can reduce cement wastage by 10% to 30%. Reduced wastage will reduce overall demand and lower material consumption and emissions across the value chain.[51]
- *Use of chemical admixtures:* Chemical admixtures have the potential to improve the performance of cement-based products even when used in small amounts. Different admixtures have different properties, which improve the performance of concrete, and in doing so reduce the quantity of cement required to achieve the desired strength of the end-product. Admixtures play an important role in adoption of new types of cements, by allowing increased use of Supplementary Cementous Materials (SCMs) and increasing the life span of structures.
    - Dispersant-based water reducers (plasticizers) and superplasticizers: These admixtures reduce the amount of water required to make concrete thereby also reducing the quantity of cement required to achieve a given strength and durability. Dispersant-based water reducers also enable the use of SCMs and fillers which results in desirable outcome in terms of water consumption.
      Using these admixtures will save water, cement and carbon: literature reviews suggest that superplasticizers used within the range of 1.3 to 4.6 kg/m^3 of concrete can reduce the quantity of cement and water required by between 10% and 30% each, with an overall reduction in emissions between 10% and 28%. This quantity will differ with the type and quantity of filler used.
    - Air entraining agents: These agents are used to incorporate fine air bubbles during the mixing of mortars or concrete which helps to improve the resistance to frost action and rheology. This is effective to save materials including cement and increase material efficiency, especially mortar and concrete components which are used mainly for filling.

[49] Refer to Annex 4.15 for detailed sources.
[50] Refer to Annex 4.16 for detailed sources.
[51] Refer to Annex 4.17 for detailed sources.

These have been successfully used in the US for interior flatwork in homes where the main requirement from concrete was the finish of the product and not strength. These can be explored in the Indian context.

  - Accelerators: These admixtures enable concrete to achieve a desired strength quickly, thus allowing concretes which have high proportions of SCMs (which develop strength slowly) to reach early adequate strength required for construction.
  - Chemicals which prolong the life of concrete structures by addressing durability issues such as cracking reduction, reinforcement corrosion protection, freeze thaw protection, etc., will reduce the demand for cement in the long run by increasing the life span of the concrete structure.[52]

- *Building design*: decisions at both structural and architectural level play an important role in reducing the demand for virgin raw materials. Using tools such as building information modelling (BIM), which helps to identify wastage during early stages of construction planning, allows for better management and use of materials. This helps to reduce material consumption at the design stage. Similarly, lightweight designs can minimize the demand for materials. Design also influences the lifespan of the structures by choosing long-lasting and durable materials. It allows a structure to be built for refurbishment. Design elements which can be incorporated are modular construction, access to services to allow upgrade as technology develops, design for deconstruction, larger floor-to-ceiling heights than required to allow change of use. Design can also allow a new structure to be built for multiple uses reducing the demand for new material: as an example, using a building as an office space during the day and some other purpose at night. These interventions also help to reduce emissions associated with the production of materials, and maintenance of buildings.[53] Many of these interventions are well-known but are not mainstreamed or prioritized.

End-of-life

- Recycling: With the help of better sorting practices, construction and demolition waste can be recycled and reused in the production of concrete, which will reduce the demand for primary raw materials. Cement during in-use stage gets hydrated, and it is difficult to recycle hydrated cement. There are new technologies under development for the recycling of hydrated cement. Around 30% to 40% of cement in the end-of-life concrete stage remains un-hydrated. By using carefully designed processes, if concrete is crushed carefully and different components are separated, portions of cement which remain un-hydrated can be recovered and reused. During this process, concrete can also be recovered and recycled to be used as aggregate in road construction.[54]

[52] Refer to Annex 4.18 for detailed sources for the use of chemical admixtures.
[53] Refer to Annex 4.19 for detailed sources.
[54] Refer to Annex 4.20 for detailed sources.

Chapter 5: Conclusion and way forward

The manufacturing stage may often be the stage that generates most emissions, but it is necessary to expand the scope of efficiency improvements, to cover the entire product life cycle, in order to tap all possible avenues for reducing emissions. Interventions related to material efficiency provide avenues for GHG abatement across the value chain and are significant because benefits due to energy and process efficiencies cannot continue to deliver at the same rate.

The cement industry is one of the eight core industries of the Indian economy, and will keep growing, continuing to contribute to national greenhouse gas emissions It is a key driver of climate change, responsible for almost one-tenth of global greenhouse gas emissions. Over the years, many energy efficiency initiatives for GHG abatement have been tried, piloted and commercialized. These include but are not limited to fossil fuel switching, installation of waste heat recovery systems, use of pre-heater and kiln systems, separate raw material grinding and transition to dry kilns. The cement mix in the country has become 'greener' having moved from a large share of OPC in the early 2000s to blended cements (PPC and PSC) which have a lower greenhouse footprint compared to OPC cement.

Adoption of technologies enhancing energy and process efficiency by cement manufacturers is widespread; however, reductions in GHG emissions using these strategies will become incremental in the coming years as efficiencies come up against thermodynamic barriers.

This report had set out to establish the baseline for GHG emissions across the cement value chain. Emissions have grown at 4.4% from 154 million tonnes CO_2 eq to 217 million tonnes CO_2 eq. The largest share of emissions is at the manufacturing stage (due to clinker production and energy generation). The report then works on the premise that managing energy and process emissions at the manufacturing stage is not the only means of reducing GHG emissions. Measures in other parts of the value chain can help reduce the demand for cement, and hence emissions associated with its manufacture. Some of the interventions which can be explored further in the Indian context are:

1. To reduce overall demand:
    a. at the design stage for buildings, explore lightweight and long-lasting structures, use of modular construction techniques, design for deconstruction and designing for multiple end-uses to extend the hours a building is in use during a day.
    b. during construction by using
        i. tools during to identify and manage cement wastage during construction, use of industrialized production and pre-fabrication techniques
        ii. admixtures and fillers to reduce requirement of cement in concrete
2. At the manufacturing stage, explore potential for
    a. Clinker substitutes to reduce emissions during calcination
    b. Green hydrogen as an alternative source of energy
    c. Carbon capture and storage for process emissions
3. At the distribution stage
    a. wherever possible prefer transport by rail, followed by shipping, road and air.
    b. use dedicated freight corridors to transport raw materials and final product.
    c. adopt new fuel technologies such as biodiesels, liquified natural gas, e-methanol, e-ammonia. electric batteries, hydrogen fuel cells, battery and fuel cell hybrids should be

incorporated into the transport system. To bring about changes at a deep level, incorporate an understanding of these aspects and the significance of life cycle thinking into academic curricula in higher education. Professional courses for architects, civil and chemical engineers, material scientists and designers should be acquainted with the requirements of working in a resource-constrained world undergoing climate change.

Financial instruments and policy directives incentivizing efficient operations, processes and uses of material can motivate action by stakeholders through the value chain. Some of the recommended measures are relatively easy to implement and can bring about large benefits.

Annexes

Annex 1

HS codes

Table 10: HS codes used to collect trade data for the cement sector

	HS Code	Description
1	252100	Limestone flux
2	25231000	Cement clinkers
3	25232100	White portland cement, w/n artificially coloured
4	25232910	Ordinary portland cement, dry
5	25232920	Ordinary portland cement, coloured
6	25232930	Portland Pozzolana cement
7	25232940	Portland slag cement
8	25232990	Other portland cement nes
9	25233000	Aluminous cement
10	25239020	High alumina refractory cement
11	25239090	Other hydraulic cements nes

Annex 2

Calculation of cement consumption

The calculation of cement consumed in a given year was based on the production and trade quantities in that year.

$C_{r,i} = P_{r,i} + I_{r,i} - E_{r,i}$

where,

$C_{r,i}$ – Consumption of cement in i^{th} year

$P_{r,i}$ – Production of cement in i^{th} year

$I_{r,i}$ – Import of cement in i^{th} year

$E_{r,i}$ – Export of cement in i^{th} year

Annex 3

Detailed emissions calculations

General

The general formula used to calculate emissions is given below.

$$\textit{GHGs emissions} = \textit{Activity Data} \times \textit{Emission factor (EF)}$$

Where, activity data refers to the amount of resource consumed, and emission factor refers to the average emission rate of a given greenhouse gas relative to the consumption of a given resource.

For this study, emissions of three greenhouse gases were considered – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

The global warming potential (GWP) of CH_4 was taken as 28 while that of N_2O is 265, based on the fifth assessment report of IPCC.[55]

Limestone mining

Limestone is primarily mined in open-cast mines in India. During this process, emissions occur due to usage of explosives for blasting and usage of high-speed diesel in machinery.

For the purpose of this study, the following assumptions have been made regarding explosive use:

i. Only ammonium nitrate-fuel oil (ANFO) is used as an explosive in limestone mines
ii. All NOx emissions from ANFO use are in the form of nitrous oxide (N_2O)

Explosive consumption data were obtained from the annual 'Indian Mineral Industry at a Glance' report published by the Indian Bureau of Mines.[56] The N_2O emission factor of ANFO was obtained from data published by the United State Environmental Protection Agency (US EPA).[57]

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[55] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf
[56] Data obtained from various issues of 'Indian Mineral Industry at a Glance' published by Indian Bureau of Mines.
2010-11: Data unavailable. The average explosive consumption per tonne of limestone mined was calculated based on explosive consumption in the years 2011-12 to 2014-15, 2016-17 and 2017-18. This value was used to estimate the explosive consumption in this year.
2011-12: Indian Bureau of Mines (2015). Indian Mineral Industry at a Glance 2012-13. Available at: https://ibm.gov.in/writereaddata/files/05122015104537IMIG%202012-13.pdf
2012-13: Indian Bureau of Mines (2015). Indian Mineral Industry at a Glance 2013-14. Available at: https://ibm.gov.in/writereaddata/files/03282016115329IMIG%202013-14.pdf
2013-14: Indian Bureau of Mines (2016). Indian Mineral Industry at a Glance 2014-15. Available at: https://ibm.gov.in/writereaddata/files/07202017150501IMIG%202014-15_final_release.pdf
2014-15: Indian Bureau of Mines (2018). Indian Mineral Industry at a Glance 2015-16. Available at: https://ibm.gov.in/writereaddata/files/01282019180807IMIG%202015-16_Final_release_280119.pdf
2015-16: Data unavailable. The average explosive consumption per tonne of limestone mined was calculated based on explosive consumption in the years 2011-12 to 2014-15, 2016-17 and 2017-18. This value was used to estimate the explosive consumption in this year.
2016-17: Indian Bureau of Mines (2020). Indian Mineral Industry at a Glance 2016-17. Available at: https://ibm.gov.in/writereaddata/files/08252020174215IMIG-2016-17_Final.pdf
2017-18: Indian Bureau of Mines (2020). Indian Mineral Industry at a Glance 2017-18. Available at: https://ibm.gov.in/writereaddata/files/09152020150205IMIG-2017-18.pdf
2018-19: Data unavailable. The average explosive consumption per tonne of limestone mined was calculated based on explosive consumption in the years 2011-12 to 2014-15, 2016-17 and 2017-18. This value was used to estimate the explosive consumption in this year.
[57] US EPA (1995). AP-42: Compilation of Air Emissions Factors – Chapter 13.3 - Explosives Detonation. Available at: https://www3.epa.gov/ttnchie1/ap42/ch13/final/c13s03.pdf

The average high-speed diesel consumed by limestone mines was estimated by referring to average diesel consumption reported by three Indian limestone mines in their pre-feasibility reports.[58] The calorific value of diesel was obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.[59] The emissions factors of diesel were obtained from the IPCC Emission Factor Database.[60]

Emissions from transport within the mines are estimated to be 5% of the total emissions from limestone mining.

Table 11 shows the emissions from limestone mining in 2018-19.

Table 11: Emissions from limestone mining in 2018-19

Activity	Activity data	Emission Factor			Emissions (million tonnes)			
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2 eq
Explosive use	45,993 tonnes	-	-	8 kg N_2O/tonne ANFO	-	-	0.000368	0.098
Diesel use	1,52,24,43,482 litres	74.1 tCO_2/TJ	0.003 tCH_4/TJ	0.0006 tN_2O/TJ	4.01	negligible	0.001	4.02
Transport within mines	-	-	-	-	0.22	-	-	0.22

Coal and lignite mining

[58] Mysore Housing Co. Pvt. Ltd. (n.d.). Pre-feasibility report - Ittigehalli limestone mine. Available at: http://environmentclearance.nic.in/writereaddata/Online/TOR/26_Jun_2018_1807559801CVFL0QMpfrofIttigehallilimestonemine.pdf
Venkateswara Cements Ltd (2017). Pre-feasibility report of limestone mine - Valajanagaram. Available at: http://www.environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=wufNt9Xm7/LQu/7epnZABnpIQg9ItHTMPqgorKvCk0Q4sWNljUsKpTxQuHEUKBXNI4zGclM4knOfQGZbvKU/vJCzRY7AQBD4WJj2voZQhcQ=&FilePath=93ZZBm8LWEXfg+HAlQix2fE2t8z/pgnoBhDlYdZCxzUlDadBGu7t8v4JoQvNU6UBlSmL0YQ7WQYaxkvlQvexKQ==
Major Mines and Minerals Corporation (n.d.). Pre-feasibility report of limestone mine – Alambadi. Available at: http://www.environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=eqLfnr4hRd6nCv/GkwXB4HeWDSt5O9buVkWWF8Q96AqUxPZ7htr4XJaovVgjEzpCwFUFxXItrQUf04fVRGujz2z1kZYfEW1Xw/4P+e09lWQ=&FilePath=93ZZBm8LWEXfg+HAlQix2fE2t8z/pgnoBhDlYdZCxzUlDadBGu7t8v4JoQvNU6UBlSmL0YQ7WQYaxkvlQvexKQ==
[59] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 2, Chapter 1 – Introduction. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf
[60] CO2 EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117776. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
CH4 EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117830. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
N2O EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117884. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

Emissions from coal and lignite mining were estimated using the methodology followed by GHG Platform India (Table 12). During mining, emissions occur due to the use of lubricant, high speed diesel and electricity.

Data on specific consumption of lubricant, high speed diesel and electricity per tonne of coal/lignite produced were obtained from the annual report of Central Coalfields Ltd.[61] The emission factor of lubricant was obtained from the GHG Platform.[62] The calorific value of diesel was obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[63] while the emission factors were obtained from the IPCC Emission Factor Database.[64] It was assumed that grid electricity was used at the mines, hence the national grid emission factor published by the Central Electricity Authority[65] was used to calculate emissions from electricity use.

Emissions from transport within the mines are estimated to be 5% of the total emissions from coal and lignite mining.

Table 12: Emissions from coal and lignite mining in 2018-19

Activity	Activity data	Emission Factor			Emissions (million tonnes)			
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2 eq
Lubricant use	654 tonnes	73.3 tCO2/tonne	-	-	0.48	-	-	0.48
Diesel use	1,29,91,449 litres	74.1 tCO_2/TJ	0.003 tCH_4/TJ	0.0006 tN_2O/TJ	0.034	negligible	negligible	0.034
Electricity use	12,29,06,740 kWh	0.79 tCO2/MWh	-	-	0.097	-	-	0.097
Transport within mines	-	-	-	-	0.009	-	-	0.009

Cement production

[61] Central Coalfields Limited (2007). Annual Report & Accounts 2006-07. Available at: https://www.centralcoalfields.in/prfnc/pdf/a_rep_2006_07.pdf

[62] Gupta, V., Biswas, T., Janakiraman, D., Ganesan, K., (2019). Greenhouse Gases Emissions of India (subnational estimates): Manufacturing Sector (2005-2015 series) dated September 19, 2019, Retrieved from http://ghgplatform-india.org/data-and-emissions/industry.html

[63] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 2, Chapter 1 – Introduction. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

[64] CO2 EF: Emission Factor ID: 117776. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
CH4 EF: Emission Factor ID: 117830. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
N2O EF: Emission Factor ID: 117884. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[65] Central Electricity Authority (2021). CO2 Baseline Database for the Indian Power Sector. User Guide – Version 16.0. Available at: https://cea.nic.in/wp-content/uploads/baseline/2021/06/User_Guide_ver_16_2021-1.pdf

Industrial Processes and Product Use (IPPU) emissions from cement production were estimated using the Tier 1 method of calculating cement production emissions recommended by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Table 13).[66] This entails calculating the emissions by estimating clinker production through use of cement production data and clinker-to-cement ratios. The India specific emission factor for clinker was obtained from the IPCC Emission Factor Database.[67]

Emissions for fuel use and electricity consumption were estimated using the consumption data obtained from the Coal Directory of India[68] and emission factors of coal[69], lignite[70] and petcoke[71] obtained from the GHG Platform and the IPCC Emission Factor Database.

Emissions from transport within the plant are estimated to be 5% of the total emissions from cement production.

Table 13: Emissions from cement production in 2018-19

Activity	Activity data	Emission Factor			Emissions (million tonnes)			
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2 eq
Clinker production	23,86,82,026 tonnes	0.5299 tonne CO2/ tonne clinker	-	-	126.5	-	-	126.5
Fuel consumption								
Coal for kilns	8,608	95.63	0.01	0.0015	16.58	0.049	0.069	16.70

[66] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 3, Chapter 2 - Mineral Industry Emissions. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf

[67] India specific CO_2 emission factor for cement production (per clinker, CKD included) – IPCC Emission Factor Database (EFDB) - Emission Factor ID: 225331. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[68] Coal Controller's Organisation (2021). Coal Directory of India 2019-20. Available at http://www.coalcontroller.gov.in/writereaddata/files/download/coaldirectory/CoalDirectory2019-20.pdf

[69] Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). Greenhouse Gas Emission Estimates from the Energy Sector in India at the Sub-national Level (Version/edition 2.0). New Delhi. GHG Platform India Report - CSTEP. Available at: http://www.ghgplatform-india.org/methodology-electricityenergy-sector

[70] CO2 EF: Mohan, R.R., Dharmala, N., Ananthakumar, M. R., Kumar, P., Bose, A. (2019). Greenhouse Gas Emission Estimates from the Energy Sector in India at the Sub-national Level (Version/edition 2.0). New Delhi. GHG Platform India Report - CSTEP. Available at: http://www.ghgplatform-india.org/methodology-electricityenergy-sector
CH4 EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117847. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
N2O EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117901. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[71] CO2 EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117783. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
CH4 EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117837. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php
N2O EF: IPCC Emission Factor Database (EFDB) - Emission Factor ID: 117891. Database can be accessed at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

		tCO2/TJ	tCH4/TJ	tN2O/TJ				
Lignite	885	105.97 tCO2/TJ	0.01 tCH4/TJ	0.0015 tN2O/TJ	0.92	0.002	0.003	0.92
Petcoke	12,708	97.5 tCO2/TJ	0.003 tCH4/TJ	0.0006 tN2O/TJ	40.27	0.035	0.066	40.37
Coal for CPP	7,495	96.76 tCO2/TJ	0.01 tCH4/TJ	0.0015 tN2O/TJ	12.39	0.036	0.051	12.48
Transport within plant	-	-	-	-	10.37	-	-	10.37

Distribution

In India, cement is distributed by rail, road and sea. Data on mode-wise distribution of cement were available only for the years 2002-03 to 2008-09 (data from CMA[72]).

For 2009-10 to 2018-19, the percentage share of rail in the distribution of cement was obtained from the Indian Railway's annual Yearbooks.[73] Due to unavailability of data on transport by sea, the percentage of sea transport in 2008-09, obtained from CMA, was kept constant across the remaining years (2009-10 to 2018-19). The remaining percentage was assumed to be that of road transport.

Due to the low share of sea transport and the unavailability of activity data, emissions have only been estimated for rail and road transport.

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[72] Data from Cement Statistics (various issues) published by Cement Manufacturers' Association. Data extracted from Kuriachan, B. A. (2011). *Growth and technological changes in cement industry* [Doctoral dissertation, Mahatma Gandhi University]. Shodhganga. https://shodhganga.inflibnet.ac.in/handle/10603/26021

[73] Data obtained from various issues of the annual Yearbook of the Indian Railways.
2010-11: Railway Board (n.d.). Indian Railways Year Book 2011-12. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1274
2011-12: Railway Board (n.d.). Indian Railways Year Book 2012-13. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1451,1454
2012-13: Railway Board (n.d.). Indian Railways Year Book 2013-14. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1554,1555
2013-14: Railway Board (n.d.). Indian Railways Year Book 2014-15. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1683,1688
2014-15: Railway Board (n.d.). Indian Railways Year Book 2015-16. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1817,1819
2015-16: Railway Board (n.d.). Indian Railways Year Book 2016-17. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1964,1966
2016-17: Railway Board (n.d.). Indian Railways Year Book 2017-18. Available at: https://indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/pdf_annual_report/Railway%20Year%20Book_2017_18.pdf
2017-18: Railway Board (n.d.). Indian Railways Year Book 2018-19. Available at: https://indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/Year_Book/Year%20Book%202018-19-English.pdf
2018-19: Railway Board (n.d.). Indian Railways Year Book 2019-20. Available at: https://indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/Annual-Reports-2019-2020/Year-Book-2019-20-English_Final_Web.pdf

Rail transport: Emissions from rail transport were estimated based on the net tonne kilometers data for cement transport via rail which were obtained from the Annual Statistical Statements of the Indian Railways.[74] India specific emission factor for freight transport by rail was obtained from the India GHG Program.[75]

Road transport: The net tonne kilometers travelled by road were estimated based on the average lead for the movement of cement by road.[76] For the purpose of this study, it was assumed that cement is transported by Heavy Duty Vehicles (HDVs) with a gross capacity of 12 tonnes. The India specific emission factor for freight transport by HDVs on road was obtained from the India GHG Program.[77]

Table 14: Emissions from distribution of cement by rail and road in 2018-19

Activity	Activity data	Emission Factor			Emissions (million tonnes)			
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2 eq
Rail transport	67,81,83,55,000 net tonne km	0.00996 kg CO_2 / tonne km	-	-	0.68	-	-	0.68
Road transport	75,88,81,63,509 net tonne km	0.061458333 kg CO_2 / tonne km	-	-	4.66	-	-	4.66

Due to the unavailability of transport data of raw materials for cement production, emissions from transport of raw materials have not been estimated.

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[74] 2010-11: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2010-11. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1179
2011-12: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2011-12. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1276
2012-13: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2012-13. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1451,1456
2013-14: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2013-14. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1554,1559
2014-15: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2014-15. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1683,1689
2015-16: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2015-16. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1817,1822
2016-17: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2016-17. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,1964,1967
2017-18: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2017-18. Available at: https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,554,2202
2018-19: Railway Board (n.d.). Indian Railways Annual Statistical Statements 2018-19. Available at: https://indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/2018-19/Stat_Annual_Statement_2018-19.pdf

[75] India GHG Program (2015). India Specific Rail Transport Emission Factors for Passenger Travel and Material Transport. Available at: https://indiaghgp.org/sites/default/files/Rail%20Transport%20Emission.pdf

[76] National Transport Development Policy Committee (2014). India Transport Report – Moving India to 2032 – Volume II. Available at: https://niti.gov.in/planningcommission.gov.in/docs/reports/genrep/NTDPC_Vol_02.pdf

[77] India GHG Program (2015). India Specific Road Transport Emission Factors. Available at: https://shaktifoundation.in/wp-content/uploads/2017/06/WRI-2015-India-Specific-Road-Transport-Emission-Factors.pdf

In-use

CO_2 uptake due to carbonation during the in-use stage was estimated using the Tier 1 method developed by IVL Swedish Environmental Research Institute.[78]

The annual uptake during the service life of concrete structures is estimated to be 20% of the emissions from clinker production (calcination emissions).

CO_2 uptake due to carbonation in in-use stage = 0.20*calcination emissions

Emissions from clinker production (calcination emissions) in 2018-19 amounted to 126.48 million tonnes CO_2 eq. Based on the formula mentioned above, the CO_2 uptake was estimated to be 25.3 million tonnes CO_2.

Annex 4
Data sources

4.1 Cement industry capacity and production

Data for capacity and production were obtained from various issues of the annual Indian Minerals Yearbook published by the Indian Bureau of Mines.

2006-07: Indian Bureau of Mines (2012). Indian Minerals Yearbook 2011 (Part- III: MINERAL REVIEWS). Available at: http://ismenvis.nic.in/Database/Indian_mineral_book2011_1625.aspx

2007-08: Indian Bureau of Mines (2013). Indian Minerals Yearbook 2012 (Part- III: MINERAL REVIEWS). Available at: http://ismenvis.nic.in/Database/Indian_Minerals_Yearbook_2012_Vol-III_4734.aspx

2008-09: Indian Bureau of Mines (2015). Indian Minerals Yearbook 2013 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=401

2009-10: Indian Bureau of Mines (2015). Indian Minerals Yearbook 2014 (Part- III: MINERAL REVIEWS). Available at: http://ismenvis.nic.in/Database/Indian_Minerals_Yearbook_2014_Vol-III_11421.aspx

2010-11: Indian Bureau of Mines (2017). Indian Minerals Yearbook 2015 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=871

2011-12: Indian Bureau of Mines (2018). Indian Minerals Yearbook 2016 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=882

2012-13: Indian Bureau of Mines (2018). Indian Minerals Yearbook 2017 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=1008

[78] Stripple, H.; Ljungkrantz, C.; Gustafsson, T.; Andersson, R. *CO_2 Uptake in Cement-Containing Products. Background and Calculation Models for IPCC Implementation*, 1st ed.; Report number: B 2309; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2018. Available at: https://www.ivl.se/english/ivl/publications/publications/co2-uptake-in-cement-containing-products---background-and-calculation-models-for-ipcc-implementation.html

2013-14: Indian Bureau of Mines (2019). Indian Minerals Yearbook 2018 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=1347

2014-15 to 2018-19: Indian Bureau of Mines (2021). Indian Minerals Yearbook 2019 (Part- III: MINERAL REVIEWS). Available at: https://ibm.gov.in/?c=pages&m=index&id=1474

4.2 Cement mix

Data for cement mix were obtained from the following sources:

2002-03 to 2008-09: Data from Cement Statistics (various issues) published by Cement Manufacturers' Association. Data extracted from Kuriachan, B. A. (2011). Growth and technological changes in cement industry [Doctoral dissertation, Mahatma Gandhi University]. Shodhganga. Available at: https://shodhganga.inflibnet.ac.in/handle/10603/26021

2009-10: Data unavailable. Assumed to be same as 2010-2011 data.

2010-11, 2015-16 and 2016-17: WBCSD, (2018). Low Carbon Technology Roadmap for the Indian Cement Sector: Status Review 2018. Available at: https://docs.wbcsd.org/2018/11/WBCSD_CSI_India_Review.pdf

2011-12 to 2014-15: Data unavailable. Assumed to be same as 2015-16 data.

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Confederation of Indian Industry

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering Industry, Government and civil society, through advisory and consultative processes.

CII is a non-government, not-for-profit, industry-led and industry-managed organization, with around 9000 members from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from 286 national and regional sectoral industry bodies.

For more than 125 years, CII has been engaged in shaping India's development journey and works proactively on transforming Indian Industry's engagement in national development. CII charts change by working closely with Government on policy issues, interfacing with thought leaders, and enhancing efficiency, competitiveness and business opportunities for industry through a range of specialized services and strategic global linkages. It also provides a platform for consensus-building and networking on key issues.

Extending its agenda beyond business, CII assists industry to identify and execute corporate citizenship programmes. Partnerships with civil society organizations carry forward corporate initiatives for integrated and inclusive development across diverse domains including affirmative action, livelihoods, diversity management, skill development, empowerment of women, and sustainable development, to name a few.

As India completes 75 years of Independence in 2022, it must position itself for global leadership with a long-term vision for India@100 in 2047. The role played by Indian industry will be central to the country's progress and success as a nation. CII, with the Theme for 2022-23 as Beyond India@75: Competitiveness, Growth, Sustainability, Internationalisation has prioritized 7 action points under these 4 sub-themes that will catalyze the journey of the country towards the vision of India@100.

With 62 offices, including 10 Centres of Excellence, in India, and 8 overseas offices in Australia, Egypt, Germany, Indonesia, Singapore, UAE, UK, and USA, as well as institutional partnerships with 350 counterpart organizations in 133 countries, CII serves as a reference point for Indian industry and the international business community.

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