Carbon Footprint Analysis of Cement Production in India

Sunita Kumari
DCRUST, Civil Engineering Department

Saurabh Jaglan
DCRUST, Civil Engineering Department

Arti Chouksey
DCRUST, Civil Engineering Department

Rinku Walia
IKGPTU, Civil Engineering Department

他

https://doi.org/10.5109/7326930

出版情報：Evergreen. 11 (4), pp.2881-2889, 2024-12. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan
バージョン：

Carbon Footprint Analysis of Cement Production in India

Sunita Kumari[1], Saurabh Jaglan[1], Arti Chouksey[1], Rinku Walia[2], Aman Ahlawat[1], Atul Garg[1], Manvendra Verma[3]

[1]DCRUST, Civil Engineering Department, Murthal, Sonipat, Haryana, India

[2]IKGPTU, Civil Engineering Department, Kapurthala, Jalandhar, Punjab, India

[3]GLA, Civil Engineering Department, Mathura, Uttarpardesh, India

*Author to whom correspondence should be addressed:
E-mail: sunitakumari.civil@dcrustm.org

(Received May 23, 2024; Revised September 2, 2024; Accepted October 4, 2024).

Abstract: As the global imperative to mitigate climate change grows, the cement industry becomes a focal point due to its significant carbon dioxide (CO_2) emissions. This study seeks to evaluate the carbon emission factors associated with direct manufacturing, manufacturing processes, neat emissions, and the entire life cycle of cement production, with a special focus on raw material extraction and cement manufacturing within cement plants. This study uses a variety of units, including raw material extraction rates, fuel consumption metrics, electricity usage data, transportation distances, and concrete life cycle assessments, to provide a comprehensive understanding of the carbon footprint inherent in each stage of cement production. It is concluded that the carbon dioxide emission factor with clinker is 0.3838t/ton of limestone and 0.4373t/per ton of cement based on manufacturing neat emission and the life cycle of cement in the cement industries. By taking a comprehensive approach that considers both direct and indirect emissions, stakeholders can make decisions incorporating advanced technology, process modification, and sustainable materials and practices to reduce the carbon intensity of cement manufacturing while advancing sustainability goals.

Keywords: Carbon dioxide emission; Cement; Manufacturing Process; Limestone; Clinker

1. Introduction

Cement, a fundamental construction component, has played a pivotal role in shaping the modern built environment. As societies evolve and urbanize, the demand for robust and sustainable infrastructure has intensified, making cement a crucial material for meeting these challenges. According to the Statista Research Department 2023 report, the volume of cement production has increased by 206 million metric tons to 381 million metric tons in the last two decades[1]. At Present, India is having 333 cement manufacturing units out of which 150 are large integrated cement plants, 116 are griding, 62 mini cement plant and 5 clinkerization plants. Where, Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Rajasthan, and Gujarat, are the highest cement manufacturer states in India. This versatile binding agent is utilized in many construction applications, ranging from towering and expansive bridges to residential homes and essential public amenities. The per capita demand for 200-250 kg cement is intricately tied to global population growth and urbanization[2]. As more people migrate to cities, the need for housing, transportation networks, and commercial spaces has surged[3]. This has led to consistent and escalating demand for cement as a primary construction material.

Additionally, emerging economies and developing nations are investing heavily in infrastructure projects, that further contributing to the global demand for cement[4,5]. Per capita consumption in India is 200- 250 kg/yr. as compared to Global per capita consumption of 500-550kg[6]. it is expected to grow by 8 to 15 percent over the next few years, driven by rural housing demand and the government's strong focus on infrastructure development and a multimodal transportation network. The increased demand for cement directly boosts carbon dioxide emissions.

Cement production requires high-temperature processes, particularly the calcination of limestone (calcium carbonate), which produces clinker, the primary ingredient in cement. This calcination process produces CO_2 as a byproduct of the chemical reaction in which limestone decomposes into lime (calcium oxide) and CO_2. Furthermore, the grinding of raw materials, the production of clinker in kilns, and the grinding of cement all require significant energy inputs, primarily from fossil fuels like coal and natural gas—the combustion of these fuels releases CO_2 directly into the atmosphere. Limestone, 95% of the raw material used, plays an indispensable role in clinker production, contributing to the strength, durability, and overall quality of Portland cement. Its calcination process and fluxing properties ensure the formation of essential clinker compounds. Figure 1 shows the production of limestone and Cement Production of limestone & Cement in India. In 2021, Global cement production was 4.37 billion tons, while in India it was 349.12 metric ton which is the world's second-largest cement manufacturing country[7)]. State wise CO_2 emission from cement plant is not available. Production of cement is 10 to 15% less than the limestone used. In the upcoming decade, the Indian cement industry is poised for remarkable growth, with anticipated demand set to soar to 2.5 to 2.7 times its current volumes, reaching an estimated 550 to 600 million metric tons per annum (MTPA) by 2025[8)]. Meanwhile, China maintains its dominance, consuming a staggering 2119 million tons in 2022, representing 52% of global demand. The second-largest consumer, with 387.335 million tons in 2022, experienced an 8.1% expansion in 2023. This growth is attributed to persistent urbanization and industrialization trends, supporting both consumption and a rapid pace of capacity expansion for the foreseeable future.

On the other hand, demand in the US, the world's third-largest consumer, faced a slight setback, with an estimated 2.7% decline in 2023, reaching 108 million tons. This dip is attributed to challenges posed by interest rates, impacting homebuilders and homebuyers. Despite this setback, the global cement landscape showcases dynamic trends, with each region navigating its unique set of factors influencing demand and consumption[9)].

Cement production also requires transporting raw materials, fuels, and finished products over long distances, contributing to additional CO_2 emissions. Because cement markets are global, raw materials can be sourced in one region, transported to manufacturing facilities in another, and distributed to construction sites in various locations, resulting in significant transportation emissions.

Concrete is made by mixing cement with aggregates (such as sand and gravel) and water, and the chemical reaction between cement and water emits additional CO_2. Furthermore, the carbonation of concrete over time results in the absorption of atmospheric CO_2, but this process is relatively slow, with 100 years of concreting considered. Assessment of CO_2 includes the emission during the life cycle of cement (Cradle to Grave), from the quarry of raw material to the demolition of concrete[11)]. The direct emissions of CO_2 from clinker, OPC, PPC, PSC, and composite cement are 779kgCO_2/t clinker, 740 kgCO_2/t, 507kgCO_2/t, 312kgCO_2/t and 315kgCO_2/t of cement respectively. While for the manufacturing process, these are 850kgCO_2/t clinker, 84_2kgCO2/t, 582CO_2kg/t, 318kgCO_2/t, and 418kgCO_2/t of cement respectively[10)]. In China, manufacture direct emission, manufacture direct process manufacture neat emission of CO2 for clinker are 0.7628t/t, 0.8143t/t, and 0.4878t/t of clinker respectively. Similarly, for OPC these values are 0.7265t/t, 0.8077t/t, and 0.4646t/t of cement respectively. The CO_2 emission of the Cement life cycle is 0.5884t/t of cement as calculated by W. Shen[13)].

The objective of this study is to comprehensively quantify the carbon emissions associated with various stages of cement production, focusing on direct manufacturing, manufacturing processes, and the entire life cycle. This study is based on a detailed understanding of the carbon footprint, particularly in raw material extraction and cement manufacturing within cement plants. By utilizing a variety of metrics, including raw material extraction rates, fuel consumption, electricity usage, transportation distances, and life cycle assessments. The final output is to determine the carbon dioxide emission factors with clinker and, subsequently, propose recommendations for stakeholders to reduce the carbon intensity of cement manufacturing by incorporating advanced technology, process modification, and adopting sustainable materials.

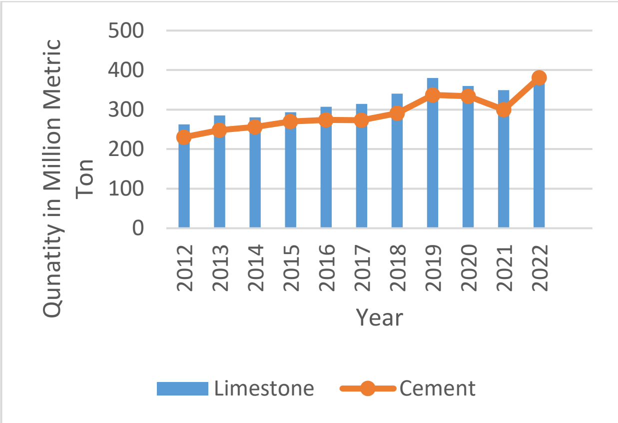

Fig. 1: Limestone and Cement consumption by the Indian cement industry

2. Manufacturing of cement

Raw materials for cement production are typically obtained from quarries or mines near the cement plant. The primary ingredient, limestone, is extracted from open-pit mines via drilling, blasting, and hauling techniques. Limestone deposits are commonly found in sedimentary rock formations and are high in calcium carbonate, making them ideal for cement production. Once extracted, limestone is crushed and screened to reduce size and remove impurities. This crushed limestone and other raw materials like clay and iron ore are then delivered to the cement plant for further processing.

Clinker, the most important component of cement, is made from a mixture of raw materials such as limestone, sand, and clay. Sand and clay provide the remaining silica, alumina, and iron requirements that are not met by limestone. The powdered raw material is thoroughly mixed and preheated to 900°C to burn impurities in the kiln. The materials are then heated to 1450°C for de-carbonation in a cement kiln, where CO_2 is liberated from the burning of limestone, and a slurry of the materials is formed. Material heating converts slurry into small balls known as clinker. Clinkers are ground into fine powder in a ball mill after cooling. Gypsum is also added in small amounts during the grinding process to control cement

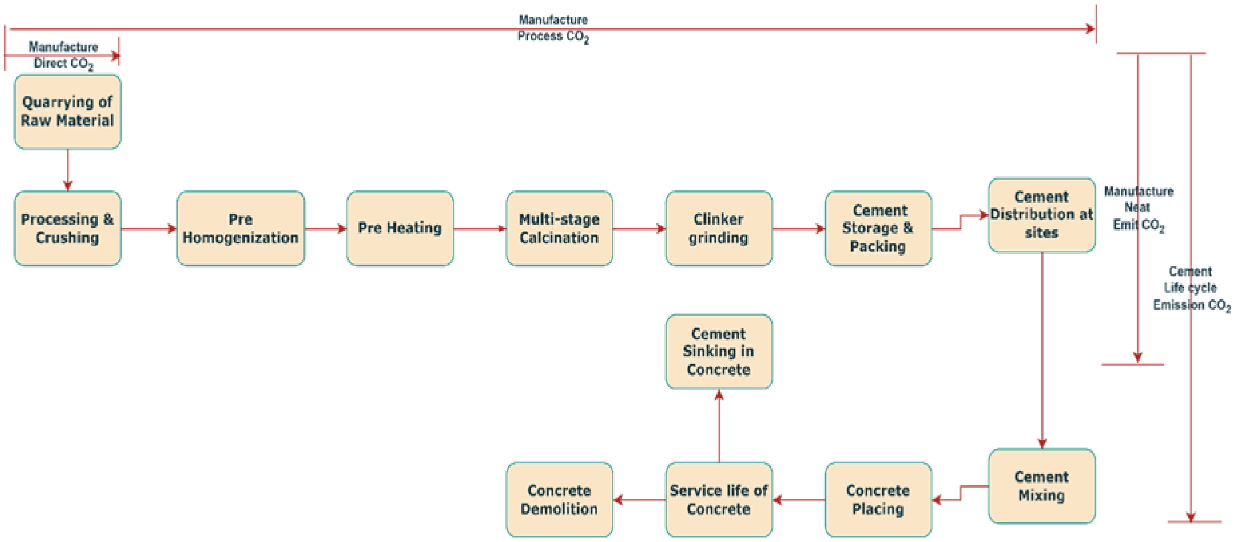

Fig.2: Manufacturing Process of Cement

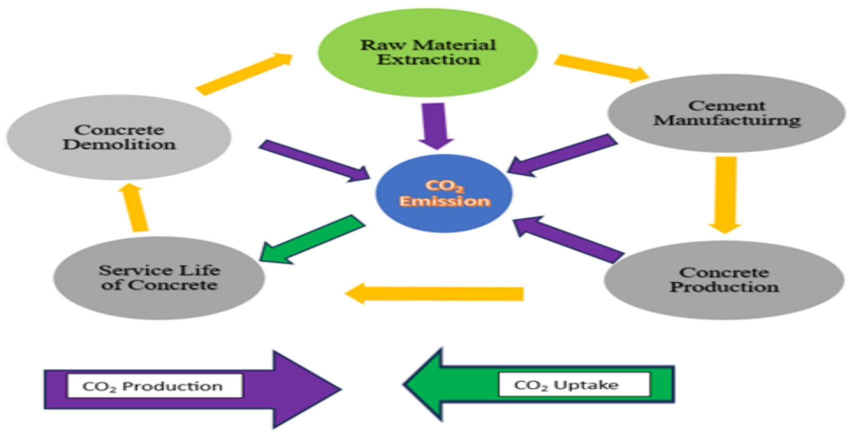

Fig. 3: Carbon Footprint during Life Cycle of Cement

setting. The manufactured cement is transported directly to silos and packaged in 50 kg bags[10,12]. After that, cement is transported to the distributor to sell for construction purposes. At the construction site, concrete mix is prepared using all ingredients like Cement, fine & Coarse aggregates, SCM, and water. The placement of concrete is done as per the infrastructure design /element. Concrete serves till any damage or renovation takes place in the structure. Carbonation sinks carbon dioxide during the concrete service life or in landfilling after demolition[13]. Further, the boundary system of Direct manufacture, Direct manufacture process, manufacture neat emission, and cement life cycle of CO_2 emission[13] is also shown in Fig. 2.

Extraction of raw material, manufacturing of cement, Concrete Production, and demolition emit CO_2 into the atmosphere while concrete during its service life uptake the CO_2 from the atmosphere which is also called the sinking of carbon dioxide[13] as shown in Fig. 3.

According to (the World Business Council for Sustainable Development[14]), the direct manufacturing process emissions source of CO_2 includes raw material - calcination, direct stationary combustion in furnaces, fossil fuels, and mobile emissions from the company-vehicle used in the cement manufacturing process. At the same time, the indirect emission is the electricity purchased for a cement manufacturing plant.

3. CO_2 emission from various units in the Indian Cement industry

(a) CO_2 emission from raw materials Carbon emission from raw materials is the summarization of Cao and MgO available in the raw materials, which can be calculated by eq. (i)

$RM\text{-}CO_2 = Mcao \times (44/56) \times Rcaco_3 + M_{MgO} \times (44/40) \times RMgco_3$ (1)

Where Cao and MgO are 65% and 2% respectively, the average percentage in the clinker. $Rcaco_3$ and $RMgco_3$ are 95% and 75% respectively. The percentage of CaO and MgO of OPC - 43 are obtained from chemical analysis of material shown in Table 1. The high percentage of CaO (57.21%) suggests that this cement is rich in calcium, a key component for strength development during the hydration process.

The SiO_2 content (20.58%) indicates a significant presence of silica, contributing to the cement's overall structure. Al_2O_3 and Fe_2O_3 together make up about 8.9%, influencing the cement's color and stability. The presence of Na_2O and K_2O indicates potential susceptibility to alkali-silica reactions, which may need attention during concrete mix design.

From above eq.1, $RM\text{-}CO_2$ emission obtained is 0.501t CO_2/t clinker and 0.4762 t/t of cement, which is slightly less than the worldwide and Indian emission of CO_2 from one ton of clinker is 0.507t /ton of clinker and 0.528t/t clinker respectively[15,16]. According to the IPCC method, the emission factor is 0.510t/t clinker without MgO[17]. With the CSI clinker-based method the emission is 0.525t/t clinker with MgO.

Table 1. Chemical composition of OPC 43

Parameter	OPC 43
SiO_2	20.58
Al_2O_3	4.98
Fe_2O_3	3.89
CaO	57.21
Na_2O	0.15
SO_2	2.54
K_2O	0.57
MgO	1.27
LOI	4.0

Use of Calcium sulphoaluminate contains a high amount of limestone and unused overburden bauxite from mining can be used as raw material to reduce two- third of the CO_2 emission[18]. The use of Geopolymer concrete instead of OPC concrete can reduce CO_2, it has good mechanical strength and durability properties[19,20,21,22].

(b) CO_2 emission from fuel used

It is the emission from the fuel used in the calcination of clinker and the machine used in the plant, except the vehicle to transport the raw materials.

$Fuel\text{-}CO_2 = P/29.307 \times EFcoal + V\,diesel \times EF\,diesel/1000$ (2)

Where P is Thermal energy consumption by the clinker system, e.g., Five stage cyclone pre-heater plus pre-calciner with energy efficient cooler, is 3.026GJ/t clinker and 3.4GJ/t cement (Including clinker) in India[23,24]. V is the total amount of diesel used in machines during cement manufacturing 1.72Lt/t clinker and 4.83 Lt/ton cement (including clinker)[25,26]. During the heating and burning process of raw materials in the kiln, decomposition reactions, transformation, and new phases occur. The cement manufacturing plant consumes approximately 70-80 percent of total energy in the form of thermal energy and the remaining energy (20-30%) is electrical energy[27,28]. Coal and Diesel emission factors are 2.4567tCO_2/t of coal and 2.764 kgCO_2/Lt of diesel[29,30]. Fuel – CO_2 emission for clinker is 0.2584t/t of clinker and 0.2455t/t of cement. The emission of CO_2 is 0.2953t/t of clinker based on fuel; the value may vary as per production technology adopted in China[17].

Using biomass, solid–derived fuel (SDF), and Refuse-derived fuel (RDF) instead of coal can reduce CO_2 emissions, Waste lubricant oils, Plastics, Used tires, Sewage sludge, Timber waste, etc. Although all fuels emit CO_2, certain alternative fuels are considered CO_2-neutral. Growing organic materials capture CO_2, which is then released when burned, resulting in zero CO_2 emissions. Using alternative materials, such as used tires, can also be considered an environmentally responsible alternative to dumping them in landfills[31,32].

(c) CO_2 emission from electricity consumption

Electric energy is required in cement plants to extract and prepare raw materials, clinker production, fuel grinding, cement grinding, and cement packaging and loading.

$ED\text{-}CO_2 = \sum M \times El \times EF\,electricity$ (3)

M= Mass of material used to manufacture one ton of cement is 1.55-ton clinker[25]. El is the electricity used in the crusher, raw mill, Kiln & cooler, and Coal mill is 40.37kWh/t, and in the Cement mill and packaging plant is 30.74kWh/t evaluated by Shakti Sustainability Energy Foundation[33]. EF electricity emission factor in India is 1.19kgCO_2/kWh as per the Electricity GHG Inventory Report[34]. Electricity consumed in the Indian cement industry is purchased from the regional grid and, therefore, is not included in the calculation. Electricity CO_2 emission is found to be 0.0749 t/t of clinker and 0.0846t/t of cement, which is generated from waste heat recovery technology. It is 0.02633t CO_2/t clinker in China because electricity consumption in the kiln is less (23.14Kwh/t clinker) than in India[17].

Developing and implementing low-carbon cement grinding technology and equipment can help reduce power consumption and up to 10% CO_2 emission while improving clinker quality[35]. Application of 10%Zelolite, 15%kaoline, or 25% combination of both can reduce CO_2 emission to a large extent due to the similar properties of cement[36].

(d) CO_2 emission from vehicles used for transportation

It summarizes CO_2 emitted while transporting raw material, gypsum SCM to the cement plant, placing fresh concrete, and disposal of C&D concrete waste.

$$TD\text{-}CO_2 = \sum M \times D \times FC \times EF\ diesel \qquad (4)$$

Where M is the mass of material transported, D is the distance covered by the vehicle. FC is the fuel consumption during transportation.

EF diesel vehicles are 0.1023 CO_2/t-km for LDV and have a loading capacity of more than 3.5T, as per India's GHG program 2015[37)]. The average distance traveled for raw material is 10km, where Gypsum and coal are 300km, admixture traveled 10km, and fresh and demolished concrete and vehicles covered 20km and 50 km, respectively. The quantity of material for manufacturing cement is considered as Raw material – 1.5t/one ton of cement, Gypsum – 0.050t/one ton of cement[23)], Coal-0.215t/one ton of clinker[32)].TD – CO2 emission of Clinker, Cement, and Concrete are shown in Table 2–

Table 2: CO_2 emission from the transportation of materials.

Product	Material	Mass (t)	D (km)	EF ($kgCO_2$/t-km)	CO_2 (t)
Clinker	Raw Material	1.50	10	0.1023	0.00153
	Coal	0.215	300	0.1023	0.00660
Cement	Raw Material	1.50	10	0.1023	0.00153
	Coal	0.215	300	0.1023	0.00660
	Gypsum	0.05	300	0.1023	0.00153
Concrete	Cement	1.00	100	0.1023	0.01023
	Fresh concrete	1.43	20	0.1023	0.00293
	Waste concrete	1.43	50	0.1023	0.00731

Transportation accounted for up to 20% of total emissions[33)].

(e)LC-CO_2 emission at the life cycle of concrete

Water is responsible for cement hydration, workability, and strength development in concrete. Therefore, the CO_2 emission from water with the cement is included during the life cycle of concrete. The total quantity of material flow in the concrete life cycle is equivalent to the mass of cement paste. The life cycle of concrete involves activities like mixing, placing, and demolition of concrete, and CO_2 emissions are 0.0004kgCO_2, 0.0025kgCO_2, and 0.000538 kgCO_2 per kg of concrete[29,30)]. This paper uses 406.604kg cement, Fine& Coarse (FA & CA) aggregates with 0.43 water–cement ratio to prepare 1 m^3 M35 grade concrete. The total quantity of material flow is 1.43, excluding the FA & CA.LC-CO_2 = 0.00492t/t cement used in concrete

(f) CO_2 sinking during carbonation (S-CO_2)

Concrete will absorb atmospheric CO_2 over time if exposed to air. This is known as carbonation, an inherent property of Portland cement-based concrete. Carbonation will occur both during and after the service life of a concrete structure. The carbonation rate may be affected if the concrete contains supplementary cementitious materials, either as part of the cement or added directly at the concrete batch plant. Limestone increases the carbonation rate by lowering the clinker content per unit volume of concrete. The paste's buffering capacity decreases because less hydration product or CaO per unit volume can be carbonated.

CO_2 absorbed by concrete (kg/m^3 concrete) = 0.75 x C CaO x M_{co_2}/M_{cao} = 0.383x C, where C is the amount of cement in 1m^3 concrete (5)

For these calculations, a lifetime of 100 years was used, with the service life of the concrete estimated to be 70 years. Carbonation of demolished concrete was calculated for 30 years[40)]. CO_2 sinking is 0.365t/t of cement.

CO_2 emission at various phases of cement production in the cement industry based on the values shown in Table 3[40,41)]:

Manufacture Direct CO_2 = RM-CO_2 + FD-CO_2…. (6)

Manufacture Process CO_2 = RM-CO_2 + FD-CO_2 + ED- CO_2 + TD-CO_2 (Cement produce) ……… (7)

Manufacture Neat Emit = RM-CO_2 + FD-CO_2 + TD-CO_2 (Cement produce) + S-CO_2……………… (8)

Cement Life Cycle Emission CO_2 = RM-CO_2 + FD-CO_2 + ED-CO_2 + TD-CO_2 (Cement produce) + S-CO_2 + LC-CO_2 + TD-CO_2 (Concrete life Cycle) …. (9)

Table 3: Emission of CO_2 at various phases of cement manufacturing

Phases	Clinker	OPC Cement
RM - CO_2	0.5012	0.4371
FD - CO_2	0.2584	0.2455
ED - CO_2	0.0749	0.0846
TD - CO_2	0.0081	0.0097
LC -CO_2	---	0.0049
TD -CO_2(Con)	---	0.0205
S - CO2 (-ve)	0.3840	0.3650

Table 4: The CO_2 emission factor of cement production

CO_2 emission from	Clinker	OPC Cement
Manufacture Direct	0.7597	0.6826
Manufacture Process	0.8427	0.7769
Manufacture Neat Emit	0.3838	0.3273
Cement Life Cycle	----	0.4373

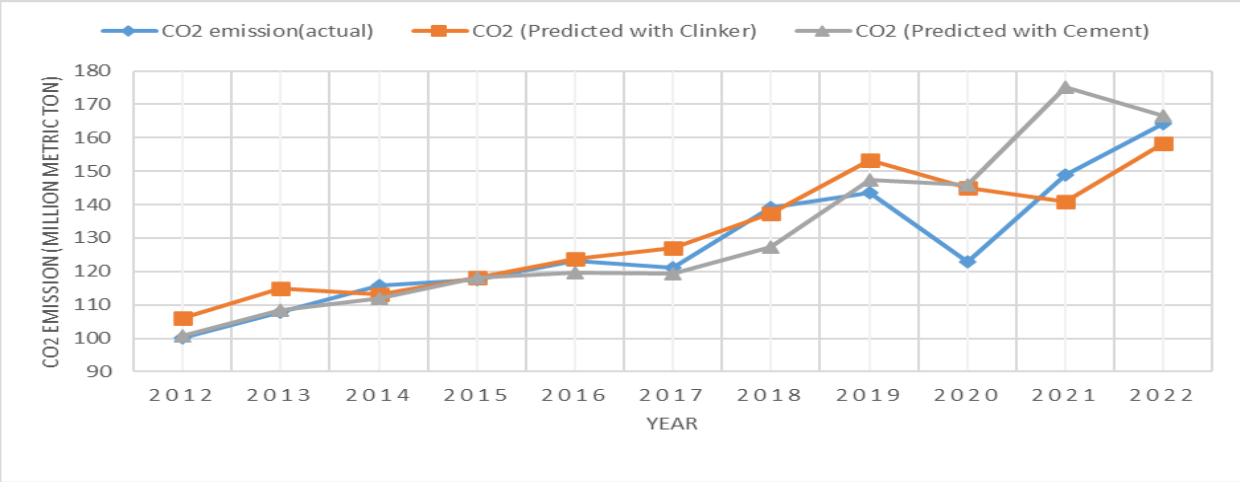

Fig. 4: CO_2 emitted from Indian Cement Industry.

Table 4 shows that CO_2 emission factors are calculated at different phases based on the inventory for cement production. The Manufacture direct CO_2 emissions factors for Clinker and cement are 0.7597t/t & 0.6826t /t respectively. It is the sum of CO_2 emissions from raw material and fuel used during calcination in machines.

The direct manufacture CO_2 emission factor is 0.0771 more for Clinker, as the quantity of raw material and material to be calcined in the kiln is 1.5 times the cement produced. The range in developing countries is 0.825t – 0.890t CO_2/t of clinker, while worldwide, it is 0.840t/t of clinker[30].

The total CO_2 emission factors during the manufacturing process of clinker and Ordinary Portland Cement are 0.842t/t clinker & 0.819t /t respectively, similar to the estimated values by researchers Parth & Shrivastava[16,42,43]. In Spain it is found to be 0.9245t/t clinker[24]. It is obtained by adding CO_2 emission from consumption of fuel and energy, during transportation of material and calcination. The manufacturing process CO_2 emission factor of clinker is 0.0658 more than the cement because it depends upon the clinker factor (the mass ratio of clinker to cement) and production technologies[44].

The Neat CO_2 emission factor of clinker includes the CO_2 emitted from raw material, fuel consumed, and transportation, except electricity used in grinding because the industry purchases it. For clinker and cement it is equivalent to 0.3838t/ton of clinker and 0.3273t/ton of cement respectively. The Neat CO_2 emission value in Spain is 0.3471t/ton of clinker [30].

The cement life Cycle Emission is the sum of CO_2 from Neat emission from cement produced and the lifecycle emission of concrete. Therefore, clinker has zero values while cement used in manufacturing concrete is0.4373t/per ton of cement.

Total CO_2 emission during cement manufacturing from the cement industry calculated by –

Total CO_2 emission (Yearly) = 0.3838 x limestone consumption in cement industries yearly…. (5)

Total CO_2 emission (Yearly) = 0.4373 x Cement produced in that year …... (6)

3.2 Assessment of Carbon emission from the Indian cement Industry

CO_2 emission from the cement industries (2011 – 2022) is assessed by equations 5 &6 based on the quantity of limestone extracted and cement produced in the respective years as shown in Fig.4. All the values of CO_2 emissions except in the years 2020 & 2021 due to COVID-19. with limestone and cement are approximately the same Limestone is 95% of the raw material; therefore, it is used to evaluate CO_2 emissions as clinker. The overall CO_2 emissions varied, with notable peaks in 2019, 2021, and 2022.CO_2 emission shows a 64 % increase in the year 2022 as compared to 2012.

CO_2 emissions per unit of clinker produced ("CO_2 (Clinker)") showed variability, reaching a peak in 2019. It offers a 49% increase in 2022 as compared to 2012.

In FY 2023 – 2024 the production of limestone is 450MMT[45] and it is predicted that CO_2 emission from the cement industry will be 172.71MMT.

4. Application of CO_2 emission factors –

Assessing carbon emission factors from cement plants is critical for understanding and mitigating the environmental impact of cement production, which is well known for its significant contribution to global carbon dioxide (CO_2) emissions. By quantifying the amount of CO_2 emitted per tonne of cement produced, stakeholders can better understand the true scope of emissions associated with cement manufacturing, providing valuable insights into its impact on climate change.

Furthermore, evaluating carbon emission factors makes comparing cement production facilities to industry standards and peers easier. This comparative analysis identifies areas for improvement and establishes targets for lowering carbon emissions, fostering a culture of continuous improvement in the industry[46].

Identifying key stages in the manufacturing process that contribute the most to CO_2 emissions, such as clinker production and energy consumption, is critical for cement plants looking to reduce their environmental impact. Adopting cleaner production technologies, such as alternative fuels, energy-efficient kilns, and carbon capture and storage systems, provides tangible pathways to emission reduction and sustainability[8)].

Furthermore, accurate carbon emission factors are critical inputs for performing life cycle assessments (LCA) on cement products. LCA assesses the

environmental impacts of products from raw material extraction to end-of-life disposal, allowing for informed decisions about sustainable procurement. This comprehensive approach ensures a thorough understanding of the environmental performance of cement products[47)].

Determining carbon emision factors is even more critical in areas with carbon pricing mechanisms or participation in carbon markets. This data is required for calculating carbon liabilities and credits associated with cement production, allowing involvement in carbon trading schemes and incentivizing cost-effective emission reduction measures[48,49,50)].

5. Conclusion

In conclusion, this study has successfully quantified the carbon emissions at various critical stages of cement production, providing a comprehensive overview of the industry's environmental impact. The identified carbon dioxide emission factors, particularly with clinker, offer precise metrics crucial for understanding and addressing the challenges associated with carbon intensity in cement manufacturing.

The findings reveal a carbon dioxide emission factor of 0.3838t/ton of limestone and 0.4373t/ton of cement based on manufacturing neat emissions and the entire life cycle of OPC cement.

The assessment is based on dry cement manufactuirng process in India. It may vary with the Chemical composition of Cao and Mgo in raw material and distance from the mining & cement indusrty which is 10km and 300km considered in the present study.

By partitialy or fully replacement of cement, use of biomass as fuel, type of vehical and decreasing travelling distance, CO_2 emission can be redce upto large extent.

The uniform emission factor underscores the need for targeted efforts to optimize transportation and explore sustainable sourcing and energy alternatives to mitigate environmental impact. Addressing these key factors across the entire production chain is imperative for the cement and concrete industry to contribute meaningfully to carbon reduction goals.

Overall, evaluating carbon emission factors from cement plants is critical for improving the sustainability of cement production. It forms the foundation of a more environmentally responsible cement industry by informing decision-making, driving innovation, and facilitating efforts to mitigate climate change.

References

1) T. Ian, “CO_2 emissions from cement manufacturing in India 1960-2022. Delhi: Energy & Environment” (2023). https://www.statista.com/statistics/1198693/carbon-dioxide-emissions-cement-manufacturing-china/. (accessed on March 2024).
2) V. Malik, M. Sharma, and S. Bandyopadhyay, “Cement Industry: Trends and Prospects”, Industry Outlook, Published by Infomerics Valuation and Rating Pvt. Ltd, pp. 1-7. (2022). https://www.infomerics.com/admin/uploads/Indian_Cement_Industry_Nov_19_2020.pdf. (accessed on November 23, 2023).
3) S. Irudaya, Rajan, and R.B. Bhagat, “Internal Migration in India: Integrating Migration with Development and Urbanization Policies,” *KNOMAD, Policy Brief*, 12, pp. 1-5. (2021).
4) E. Subiyanto, “The relationship of Cement Consumption and Economic Growth: An Updated Approach,” *European Research Studies Journal*, 23(3), 280-295 (2020). http://dx.doi.org/10.35808/ersj/1638.
5) H.U. Sverdrup, and A.H Olafsdottir, “Dynamical Modelling of the Global Cement Production and Supply System, Assessing Climate Impacts of Different Future Scenarios,” *Water Air Soil Pollution* , 234(191) 1-19 (2023). doi.org/10.1007/s11270-023-06183-1.
6) Systematix, “Indian Cement Industry. Delhi,” published by Systematix Shares and Stocks (India) Limited,” (2021). https://intra.systematixgroup.in/Institutional/IPOMail/Indian%20Cement%20Industry%20-%20IC%20-%2001-09-2021%20-%20Systematix.pdf. (accessed on October 20, 2023).
7) Jaganmohan, and Madhumitha, “Limestone production volume in India FY 2012-2023. USA: statista,” (2023). https://www.statista.com/statistics/1198693/carbon-dioxide-emissions-cement-manufacturing-china/ (accessed March 14, 2024).
8) Construction. com., “Green Building Practices with Prefabrication. Manchester: Utilities One,” (2023).
9) Cement.Com. 2024. “Cement industry looks forward to sustainable progress in 2024,”. Jakarta, Indonesia: Cement News, 1. Accessed February 26, 2024. https://www.cemnet.com/Conference/Item/193101/cemtech-asia-2024.html.
10) Global Cement and Concrete Association, “Blended Cement - Green, Durable & Sustainable - 2022,” published in April 2022, gccassociation.org (Accessed on 15August 2024)
11) Olagunju, D. Busola, and O. A. Olanrewaju, “Life

Cycle Assessment of Ordinary Portland Cement (OPC) Using both Problem Oriented (Midpoint) Approach and Damage Oriented Approach (Endpoint)", Edited by Antonella Petrillo and Fabio De Felice. (2021). doi: 10.5772/intechopen.98398.

12) Y. K. Verma, D. Ghime, B. Mazumdar, and P. Ghosh, "Emission reduction through process integration and exploration." *International Journal of Environmental Science and Tech*nology, (2023). pp.13329 - 13346.

13) W. Shen, L. Cao, Q. Li, W. Zhang, G. Wang and C. Li, "Qunatifying CO_2 emission from China's cement industry," *Renewable and Sustainable Energy Review*, 50 1004 - 1012. (2015). https://doi.org/10.1016/j.rser.2015.05.031

14) World Business Council for Sustainable Development (WBCSD, 2005). "Cement Tool Guidance Document: India Version 1.0. Delhi: TERI." (2005). https://ghgprotocol.org/sites/default/files/2023-03/India_Cement_tool_guidance.pdf. (accessed January 15, 2024).

15) M.J Gibbs, P. Soyka, D. Conneely, and M Kruger, "CO_2 Emissions from Cement Production. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories," *Industrial Processes,* pp.175-182. USA. (2000). https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_1_Cement_Production.pdf.

16) Shrivastava, K. Amit, A. Vashishth, and B. Jayant, "Deterministic approach for calculation of Carbon Footprint for Cement plants in India," *Research Square*, pp. 1-20. (2020). doi.org/10.21203/rs.3.rs-285464/v1.

17) T. Gao, M. Shen, L. Shen, F. Chen, L. Liu, and L. Gao, "Analysis on differences of carbon dioxide emission from cement production and their major determinants," *Journal of Cleaner Production,* (103)160 - 170 (2015). http://dx.doi.org/10.1016/j.jclepro.2014.11.026.

18) Negrão, L. B. Ayres, H. Pöllmann, and M. L. da Costa, "Production of low-CO_2 cements using abundant bauxite overburden," *Sustainable Maerials. and Technique,* 29. pp. 1-11 (2021) doi:10.1016/j.susmat.2021.e00299.

19) M. Verma, and M. Nigam, "Effect of FRP on the strength of geopolymer concrete,"AIP Conf. Proceeding, FSAET - 2021, 2721 020030 (2023). doi.org/10.1063/5.0154114

20) M. Nigam and M. Verma, "Effect of nan-silica on the fresh and mechanical properties of conventional concrete," *Force in Mechanics*, (10) 1-7. (2023). doi.org/10.1016/j.finmec.2022.100165.

21) R. Kumar, M. Verma, and N. Dev, "Investigation on the effect of seawater condition, sulphate attack, acid attack, freeze - thaw condition, and wetting - drying on the geopolymer cocnrete," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, (46) 2823 - 2852. (2022). doi.org/10.1007/s40996-021-00767-9.

22) U. Sharma, N.Gupta, and M. Verma, "Prediction of compressive strength of GGBFS and flyash - based geopolymer composite by linear regression, lasso regression, and ridge regression," *Asian Journal of Civil Engineering*, 24 (8) 3399 - 3411. (2023). doi.org/10.1007/s42107-023-00721-2.

23) Technical EIA Guidance Manual for Cement Industry. Delhi: IL&FS Ecosmart Limited, pp.1-185, https://dste.py.gov.in/SEIAA/pdf/Sector/Isolated_Storages.pdf. (accessed on 12 December 2023).

24) A. Mokhtar, and M. Nasooti, "A decision support tool for cement industry to select energy efficiency measures," Energy Strategy Reviews, 28, pp.1-14 (2020). https://doi.org/10.1016/j.esr.2020.100458.

25) Ei. Thwe, D. Khatiwada, and A. Gasparatos, "Life cycle assessment of a cement plant in Naypyitaw, Myanmar," *Cleaner Environment System*, 2, 1 - 9. (2021). doi.org/10.1016/j.cesys.2020.100007.

26) A. Setiawan, Md. Y. J. Purwanto, and K. Siregar, "The Life Cycle Assessment of Cement Product with Alternative Fuels Usage in Indonesia," *Journal of Natural Resources & Environment Management*, 11 (3) 474-489. (2021). doi.org/10.29244/jpsl.11.3.474-489.

27) Y. K. Verma, B. Mazumdar, and P. Ghosh, "Thermal energy consumption and its conservation for a cement production unit," *Environment Engineering Research,* 26 (3) 1 - 17 (2021). https://doi.org/10.4491/eer.2020.111.

28) S. Kumari and R. Walia, "A comparative study of life cycle assessment of sustaianble cocnrete mixes," *Journal of Materials and Engineeirng Structures*, 9. 187 - 196 (2022).

29) A. Loijos, "Life cycle assessment of concrete pavements: impacts and opportunities," Massachusetts Institute of Technology. (2011).

30) M.A. Sanjuán, M. Ángel, C. Andrade, P. Mora, and A. Zaragoza, "Carbon Dioxide Uptake by Cement-Based Materials: A Spanish Case study," *Applied Science*, 10 (339) 1-16 (2020). https://doi.org/10.3390/app10010339.

31) E. Beguedou, S. Narra, E. A. Armoo, K. Agboka, and M. K. Damgou, "Alternative Fuels Substitution in Cement Industries for Improved Energy Efficiency and Sustainability," *Energies,* 16(8) 3533 (2023). https://doi.org/10.3390/en16083533.

32) GCP Applied Technologies, "Using alternatives fuels in cement production," published September 15(2020). https://gcpat.com/en/about/news/blog/using-alternative-fuels-cement-production. (accessed on 21 December 2023).

33) SSEF (2012), "A study of Energy Efficiency in the Indian Cement Industry. Bangalore: Centre for Study

of Science, Technology and Policy," 1-184. https://shaktifoundation.in/wp-content/uploads/2017/06/A-study-of-EE-in-the-cement-industry.pdf. (accessed on November 12, 2023).

34) V. Gilani, "GHG Inventory report for Electricity generation and consumption in India," cBalance Blog. (2014). https://cbalance.in/2014/05/ghg-inventory-report-for-electricity-generation-and-consumption-in-india/. (accessed on 28 October 2023).
35) Zerbe, Rüdiger. 2024. Grinding for green goals. China: ICR Research.
36) S. A. A. Wahab, E. M. Hassan, K. S. Al-Jabri, and K. Yetilmezsoy, "Application of zeolite/kaolin combination for replacement of partial cement clinker to manufacture environmentally sustainable cement in Oman," *Environmental Engineering Research* , 24 (2) 246-253 (2019). https://doi.org/10.4491/eer.2018.047.
37) GHG, India. 2015. India- Specific -Road-Transport-Emission- Factor. Delhi: WRI-2015.
38) J. D. Bapat, "Quality of coal for Indian cement industry," *Indian Cement Review,* 28 (8): 41- 42 (2014).
39) A. A. L. Pachecoa, L. S. Oliveiraa, V. M. John, and S. C. Anguloa, "Transportation impact on CO_2 emissions of concrete: a case study in Rio Branco/Brazil," *IBRACON Structures and Material Journal*, 15 (6) 1-13. (2022). https://doi.org/10.1590/S1983-41952022000600009.
40) P. Claus, and M. Guimaraes, "The CO_2 uptake of concrete in a 100 year perspective," *Cement and Concrete Research*, 37 (9) 1348-1356 (2007). https://doi.org/10.1016/j.cemconres.2007.06.009.
41) W. Shen, L. Cao, Q. Li, W. Zhang, G. Wang, and C. Li, "Quantifying CO_2 emissions from China's cement industry," *Renewable and Sustainable Energy Reviews*, 50 (1) 1004 - 1012 (2015). http://dx.doi.org/10.1016/j.rser.2015.05.031.
42) Kumar, Parth. 2023. *Cementing possibilities.* Down to Earth, New Delhi, Published on September 27, 2023. https://www.downtoearth.org.in/news/environment/cementing-possibilities-91980. (accessed on November 15, 2023).
43) M. Antunes, R. L. Santos, J. Pereira, P. Rocha, R. B. Horta, and R. Colaço, "Alternative Clinker Technologies for Reducing Carbon Emissions in Cement Industry: A Critical Review," *Materials* ,15 (1) 1-19 (2022). http://dx.doi.org/10.3390/ma15010209.
44) K. W. Rychter, and A. Smoliński, "Multi-Case Study on Environmental and Economic Benefits through Co-Burning Refuse-Derived Fuels and Sewage Sludge in Cement Industry," *Materials*, 15(12)1-18. (2022). https://doi.org/10.3390/ma15124176.
45) Energyworld.com,"India's key mineral prodcution sees robust growth in Q1 FY 2024 - 25", published in August 2024,. https://energy.economictimes.indiatimes.com/news/coal/indias-key-mineral-production-sees-robust-growth-in-q1-fy-2024-25/112190534 (Accessed August 15, 2024).
46) S. Prakasan, S. Palaniappan, and R. Gettu, "Study of Energy Use and CO_2 Emissions in the Manufacturing of Clinker and Cement," *Journal Institute of Engineers Series A*, 1-12 (2019). doi: 10.1007/s40030-019-00409-4.
47) A. Kumar, "Present Scenario of Green Buildings in India," *International Journal of Trend in Scientific Research and Development*, 6 (5) 538 – 543 (2022). https://issuu.com/ijtsrd.com/docs/67_present_scenario_of_green_buildings_in_india.
48) C. Chea, P. Ket, L. Taing, S. Kong, D. Um, C. Taing, C. Or, S. Aun, and L.Hang, "Life-Cycle Impact Assessment of Air Emissions from a Cement Production Plant in Cambodia," *Open Journal of Air Pollution*, 11 (4) 1-19 (2022). https://doi.org/10.4236/ojap.2022.114007. (Accessed March 03, 2024).
49) S. Nie, J. Zhou, F. Yang, M. Lan, J. Li, Z. Zhang, Z. Chen, M. Xu, Hui Li, and J. G. Sanjayan, "Analysis of theoretical carbon dioxide emissions from cement production: Methodology and application". *Journal of Cleaner Production*, 334, pp.1-18 (2022). https://doi.org/10.1016/j.jclepro.2021.130270.
50) B. Bakhtyar, T. Kacemi, and Md. A. Nawaz, "A Review on Carbon Emissions in Malaysian Cement Industry," *International Journal of Energy Economics and Policy*, 7 (3) 282-286 (2017).