Climate Change and India's Building & Construction Industries: Current Status and Challenges

Mr. Vijaykumar R. Kulkarni
Founder - Director,
Low Carbon Construct Forum (LCCF)
Past President,
Indian Concrete Institute

Mr. Vijay Kulkarni has more than 40 years of experience in different spheres - design of bridges and buildings, R&D in concrete, HSC-HPC, NDT and health monitoring of structures, ready-mixed concrete, green concrete, and technical dissemination and writing He was the Principal Consultant to RMCMA and contributed to the development and implementation of the quality scheme for ready mixed concrete in India. He was the President of the Indian Concrete Institute (ICI) from 2009-2011 and is currently the Co-Chair of ICI's Technical Board. He is also the Chair of the GreenPro Concrete Cortication carried out by the CII's Green Business Centre. He is the past Editor of the Indian Concrete Journal. As the founder - Director of LCCF, he is spearheading awareness building programme on reduction of carbon footprints.

Abstract

Considering India's commitment to achieve Net Zero Carbon by 2070, the author advocates that the building and construction sectors in India should actively participate in the efforts of mitigating the carbon footprints emanating from construction. The paper provides a broad scenario of the climate change phenomenon affecting India, highlighting vulnerability of a sizeable population of the country to the extreme hydro-met disasters. The current status and the sustainability-centric measures taken by India's cement, concrete, steel and walling materials industries are described. The need to increase the contents of recycled aggregates and recycled water in construction is also highlighted. It is argued that the building and construction sectors need to supplement the government's efforts on increasing the use renewable energy and reduce operational carbon from the vast stock of the existing and new buildings and other infrastructure. The author advocates that the structural engineering fraternity in India should commence the practice of estimating the embodied carbon of different alternative designs they propose to their respective clients and encourage and convince them to choose the one that provides least amount of embodied carbon. The author also appeals to the building material manufacturers and their trade associations to evaluate the Global Warming Potentials of their products and make them available to the construction engineering fraternity.

Keywords : Building and construction, climate-change scenario, net-zero operational energy, cement, concrete, steel, walling material, recycled aggregates and water, embodied carbon .

1. Climate Change: Global Scenario

The steep rise in the population coupled with widespread industrialization and growing urbanization has not only resulted in unrestrained exploitation of non-renewable natural resources from the earth but also lead to an unprecedented rise in greenhouse gas (GHG) emissions consisting mainly of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The Intergovernmental Panel on Climate Change (IPCC), which is a scientific body comprising of the world's leading experts on climate change, has been pin-pointing the serious threat posed by GHG emissions. IPCC's Fifth Assessment Report published in 2014 highlights following key facts [1]:

- Warming of Global climate system is unequivocal. The period from 1983 to 2012 was the warmest 30-year period in the last 1400 years in the northern hemisphere.
- CO_2 emission level has increased sharply from 280 ppm in 1850 to around 403 ppm in 2016 - the highest level in 800,000 years! (see Fig 1).
- Oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1, corresponding to a 26% increase in acidity.
- Sea level has increased by 0.19m during 1901-2010 owing to melting of Arctic ice shelf
- There has been a far-reaching increase in extreme events - heat waves, cyclones, tornados, floods and droughts throughout the world.

The 2018 report by IPCC further warned that the global warming reaching 1.5ºC would be the "tipping point", causing irreversible environmental changes [2].

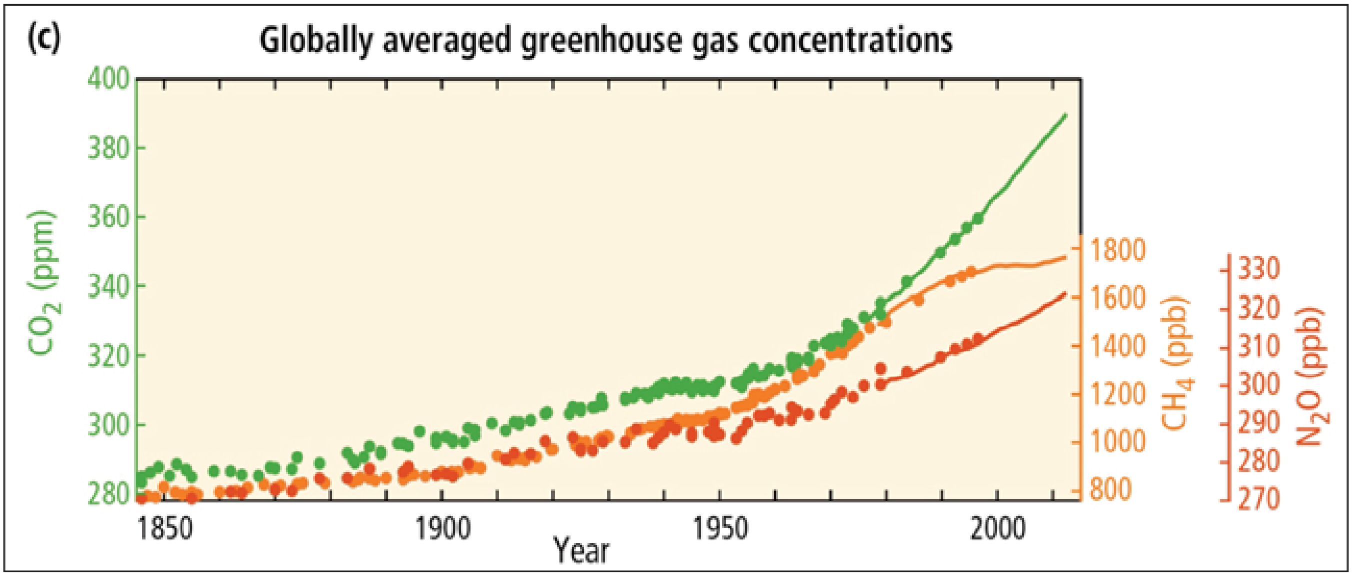

Fig 1 : Global Greenhouse gas emissions 1850-2010[1]

During the United Nation's Climate Change Conference, held in Paris (COP21) in 2015 world leaders agreed to keep the global temperature rise this century well below 2ºC above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5ºC. The Paris Agreement is a legally-binding international treaty on climate change, adopted by 196 countries.

A joint statement signed by some 11,000 leading scientists and published in *BioScience* highlighted the seriousness of the danger of climate change as:

"The climate crisis has arrived and is accelerating faster than most scientists expected. It is more severe than anticipated, threatening natural ecosystems and the fate of humanity….".[3]

The Sixth Assessment report from IPCC's Working Group II again emphasised that climate impacts are already more widespread and severe than expected and that the risks will escalate quickly with higher temperatures, often causing irreversible impacts [4]. The IPCC report from Working Group III stresses that limiting global temperature rise to around 1.5°C requires global GHG emissions to peak before 2025 at the latest, and be reduced by 43% by 2030! [5] This is indeed a gigantic task.

The latest "Synthesis Report" from IPCC on six previous findings (post 2015) warns that the planet will warm permanently by at least 1.5ºC in the next two decades in all scenarios [6]. This may leave a trail of destruction across the world due to an increase in the number of extreme weather events. The report makes a strong case for cutting carbon emissions by almost half by 2030 from the 2019 level.

2. Climate Change: Indian Scenario

2.1 India's GHG Emissions

According to a report from International Energy Agency (IEA) India happens to be the fourth largest CO_2 emitting country in the world, next to China, USA and European Union [7] . However, India's per-capita GHG emissions of less than 2 tons of CO_2e is one-third of the global average. An Indian study conducted by five well known institutions, the country's per capita GHG emission in 2030-31 is projected as varying from 2.77 tonnes to 5 tonnes of CO_2e, which is less than the world average per-capita GHG value, Fig 2[8].

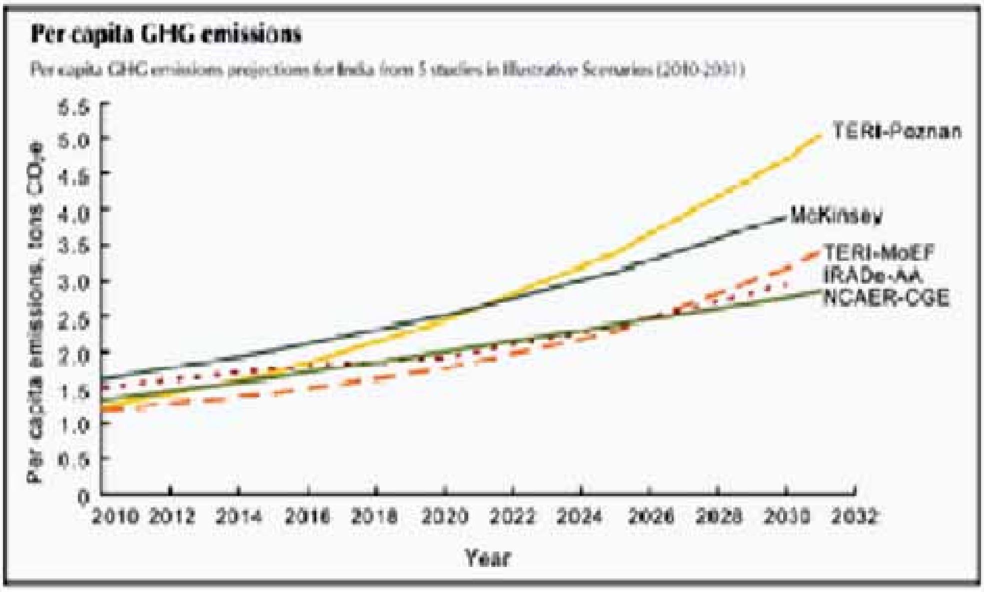

Fig 2 : India's GHG Emission Profile: Results of Five Climate Modelling Studies [8]

2.2 *Vulnerability to Extreme Events*

India is vulnerable to natural disasters - mainly hydrological and meteorological. India stands 3rd amongst the top 10 countries ranked by the occurrence of disasters during 2000-2019 [9].

During 2021, India witnessed three cyclones - Amphan, Nisarga and Nivar impacting almost the entire coastline of India, and severe floods occurred in as many as 36 cities in 12 states. While not every one of these natural disasters can be attributed to climate change, the frequency and severity of these disasters make a compelling case for linking them to the same.

India has been experiencing temperature extremes. In April 2022, India's North-West and Central parts recorded the highest temperature in 122-year! In 2023, the country experienced the hottest February since 1901.

The Centre for Science and Environment (CSE) published a report on "Climate India 2022" [10]. This report which has sourced data on extreme events from two key government sources (IMD and DMD) and also the media reports highlights that India recorded extreme weather events on 241 of the 273 days from January 1 to September 30, 2022. This means that close to 90 per cent of the first nine months of this year, India had an extreme weather event breaking in one or more parts of the country.

Recently, the Council on Energy, Environment and Water (CEEW) initiated a first-of-its-kind district-level vulnerability assessment of India, which maps exposure, sensitivity, and adaptive capacity using spatio-temporal analysis [11] .The authors of the study developed a Climate Vulnerability Index (CVI) of Indian states. One of the maps (see Fig. 3) reproduced from their report shows that more than 80 % of India's population lives in districts that are highly vulnerable to extreme hydro-met disasters!

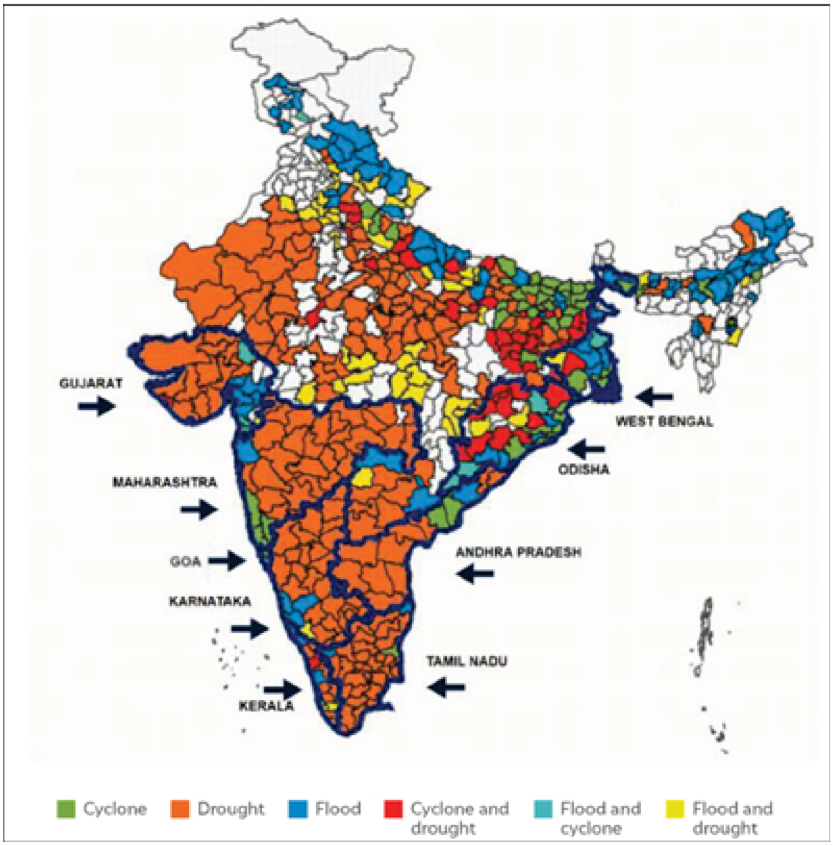

Fig 3 : Climate vulnerability Index map of India [11]

2.3 *Climate-friendly Initiatives*

Although India's contribution to GHG emissions in per-capita terms is not at all alarming, India has voluntarily pledged to cut its GHG emissions intensity by 33 to 35 %, relative to 2005 levels by 2030 during the Paris COP 15 [12]. It has also set a target to achieve about 40% cumulative electric power installed capacity from non-fossil-fuel energy resources by 2030, by installing 100 GW of solar and 60 GW of wind power by 2022. It is to the credit of India that it has been updating its climate commitments made during the Paris Conference from time-to-time, setting up challenging targets and making a steady progress in carbon mitigation.

India's climate-friendly initiatives and the country's long-term vision on the topic are presented in a 100-page document titled India's Long-term Low-Carbon Development Strategy (Fig 4) which was submitted to the United Nations Framework Convention on Climate Change (UNFCCC) during the 27th Conference of Parties (COP27) by the Ministry of Environment, Forest and Climate Change (MOEFCC) [13].

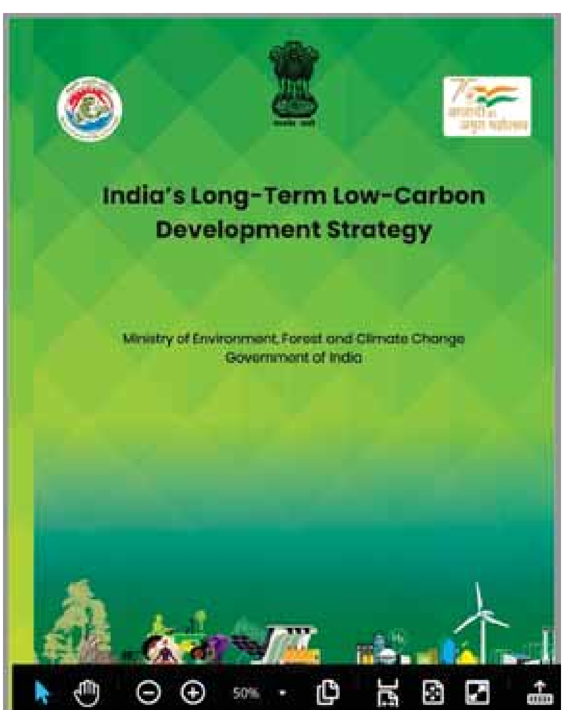

Fig 4 : India's long-term low carbon development strategy [13]

This report highlights some key premises on which India's long-term low-carbon development strategy is based. First, India's historical contribution to global GHG emissions is merely 4%, despite sustaining around 17% of the world's population. Therefore, India is entitled for a fair share of the global carbon budget and that the country needs to be adequately compensated for its carbon credit from the pre-2020 period. Second, it is emphasized that India cannot compromise on its own socio-economic development agenda and its growing energy needs. It is true that currently the fossil fuel-based power generation capacity of the country accounts for 57.7% of the total capacity [14]. However, one cannot expect India's dependency of fossil fuel-based power to diminish drastically. It is reported that the renewable energy installed capacity in India increased by a whopping 286% in the last 7.5 years [15]!

Third, despite being low carbon emitter on per capita basis, it is indeed commendable that India has voluntarily committed to explore low-carbon development pathways with following commitments:

- Meet 50% of the country's cumulative electric power installed capacity from non-fossil fuels by 2030 (Incidentally, with 42.3% of the current installed power capacity coming from non-fossil fuels1, achieving the 50% target by 2030 may not be difficult).
- Reduce emission intensity of GDP by 45% below 2005 level by 2030
- Achieve net-zero emissions by 2070.

3. Projected Development Scenario

3.1 *Prediction of Increasing Urban-centric Growth*

India is a developing country which has embarked on large-scale development of physical infrastructure and housing for its vast population.

Considering the rising aspirations of the Indian population, all-round economic development on a large-scale is an urgent necessity. A peep into the available published data on the futuristic scenario would reveal the tasks ahead.

Quoting the estimate of Department of Economic Affairs (DEA) [16], the MOEFCC report mentioned above highlights that the urban Indian population is estimated to increase sharply from 377 million in 2011 to 600 million by 2030. Admitting that urban areas are engines of growth, the report quotes a study which estimated that nearly 75% of India's GDP will be generated from the urban regions by 2030 [17]. Certain projections on Indian scenario-2040 done by the International Energy Agency (IEA) reveal that an estimated 270 million people will be added to urban Indian population in the next two decades and that around 30 billion m^2 of floor space will be required for accommodating these people, Fig 5 [18]. One can imagine the likely surge in the demand of energy-intensive materials like cement, steel, walling material, etc.

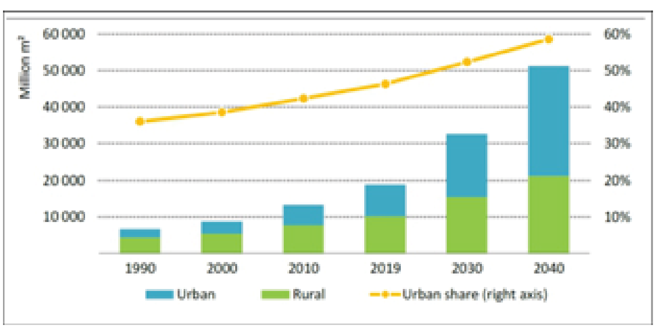

Fig 5 : Additional 30 billion m^2 of floor space will be required in urban area by 2040 [18]

3.2 *Rising Energy Requirements*

India has achieved remarkable growth in increasing the renewable energy (RE) capacity during the past few years. The share of renewable power in the country's total energy capacity has increased from 10% in 2014-15 to 23% by December 31st, 2019. The Ministry of Power, Government of India has listed the share of source-wise energy capacities under 'Power Sector at Glance' [19]. This is shown in Fig 6. It can be seen that while the fossil fuel-based capacity constitute 57.4%, the non-fossil fuel based capacity was 42.6% as on February 2023.

Installed GENERATION CAPACITY(FUELWISE) AS ON 28.02.2023

CATAGORY	INSTALLED GENERATION CAPACITY(MW)	% of SHARE IN Total
Fossil Fuel		
Coal	204,435	49.7%
Lignite	6,620	1.6%
Gas	24,824	6.1%
Diesel	589	0.1%
Total Fossil Fuel	2,36,469	57.4 %
Non-Fossil Fuel		
RES (Incl. Hydro)	168,963	41.0%
Hydro	46,850	11.4 %
Wind, Solar & Other RE	122,113	29.6 %
Wind	42,015	10.2 %
Solar	64,381	15.6 %
BM Power/Cogen	10,218	2.5 %
Waste to Energy	523	0.1 %
Small Hydro Power	4,943	1.2 %
Nuclear	6,780	1.6%
Total Non-Fossil Fuel	175,743	42.6%
Total Installed Capacity (Fossil Fuel & Non-Fossil Fuel)	4,12,212	100%

Fig 6 : Source-wise installed capacities as of Feb 2023 [19]

The estimate of projected increased urbanization is bound to lead to a further increase in the energy demand. The IEA projects that the residential electricity demand in India is likely to triple by 2050 [18]. The 19th Electrical Power Survey, conducted by the Central Electricity Authority of the Government of India estimated that the electrical power demand is going to be approximately doubled from 2021 to 2037, Fig 7 [20].

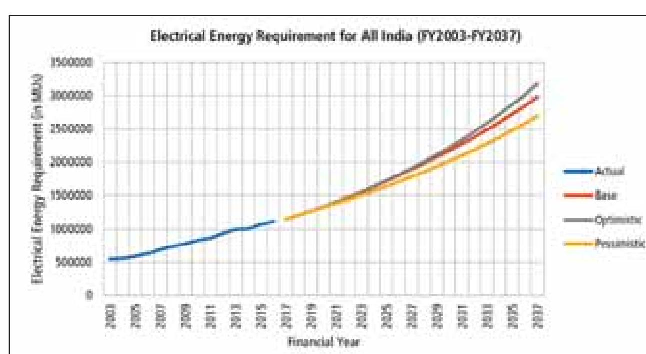

Fig 7 : Electrical energy requirement 2003-2037 [20]

During COP-26 in Glasgow India made the commitment that the country will achieve 'net zero' carbon emission by 2070. and that 50% of its electricity demand will be met with from RE sources by 2030! India also made the commitment to reduce the country's projected carbon emissions by 1 billion tonnes from now to 2030. As far as the latter is concerned, the building and construction sectors in India provide ample opportunity to mitigate emissions, and that too in a cost-effective manner as projected by the Global Green Building Council (Global GBC) [21].

4. Operational & Embodied Carbon

In the joint declaration released on November 5th, 2020, the 'India CEO Forum on Climate Change' agreed to set voluntary in-house targets and achievable GHG reduction and energy conservation goals [22] Two important goals mentioned in the declaration include achieving enhanced energy efficiency and promotion of RE.

4.1 Operational Carbon

India is fortunate to have been bestowed with a huge RE potential, estimated to be 1000 GW-plus or even more. As on February 2023, the RE capacity has touched 168.96 GW, out of which 64.38 GW is solar power capacity, 51.79 GW hydro, 42.02 GW wind and 10.77 GW bio energy [23]. Another 82.62 GW of green energy capacity is under implementation.

In recent years, there has been a steep decline in the tariff of both solar and wind energy, making the use of RE cost-effective. India has a large rooftop potential. Unfortunately, as of December 2021, only 5.87 GW of rooftop solar energy could be tapped as against the target of 40 GW. The building and construction sectors need to increase awareness in this area to achieve tangible progress.

Recently, a good beginning has been made by the Confederation of Indian Industry's Green Business Centre (CII-GBC) in launching the 'Net Zero Operational Energy' initiative. A brief article on this initiative highlights one recent exercise of retrofitting a platinum-rated building into a net-zero operational energy building, Fig. 8 [24]. It is also reported that CII-GBC has undertaken the work of more than 25 commercial building projects to convert them to net-zero operational energy buildings. Many other large commercial complexes including hotels, resorts, hospitals, malls etc. need to follow this initiative.

Besides commercial buildings, the use of rooftop solar/wind needs to percolate to the residential building sectors on a massive scale throughout India. With the financial subsidies and other measures initiated by the central and state governments, one can expect good results in the near future.

Fig 8 : The first 'Net Zero Operational Energy' building in India [24]

4.2 Embodied Carbon

The total carbon emissions occurring during the entire lifecycle of a building or a structure are classified by the European Standard EN 15978 into following five main stages (see Fig 9).

- Product and construction stage (A1-5),
- Use stage (B1-5)
- Operational energy/water use stage (B6, B7)
- End of life stage (C1-4),
- Beyond the life cycle (D)

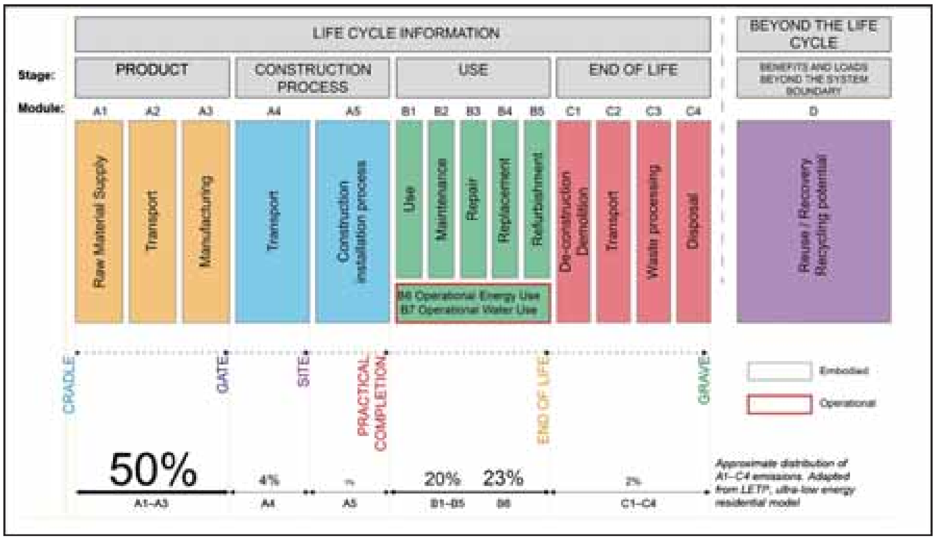

Fig 9 : Stages of lifecycle of a building or a structure as per EN 15978 [25]

The initial efforts in reducing carbon footprints were concentrated on reducing operational energy requirements (i.e B 6) by adopting energy conservation measures and energy-efficient techniques and also partly by using renewable energy. The embodied carbon is generated in all stages of the life cycle from A to D (except B 6). However, quoting the primer published by London Energy Transformation Initiative (LETI) John Orr *et al* reported that nearly 50% of embodied carbon is generated during the "Product" stage (A1-3), i. e. cradle to gate stage [25].

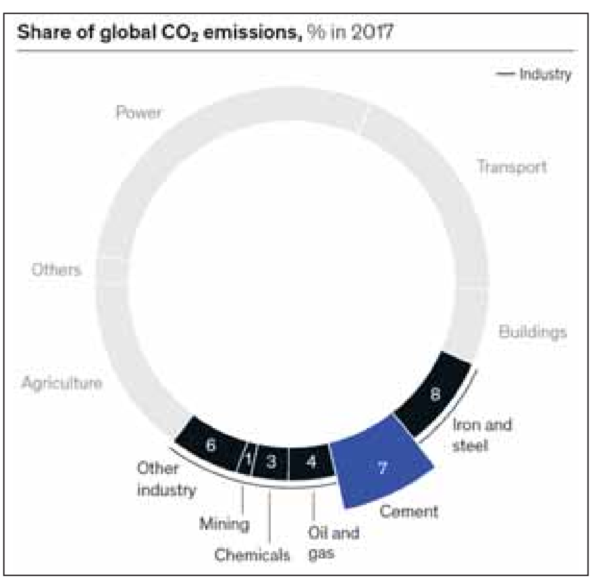

Fig 10 : Cement and iron & steel account for 15% carbon emissions globally [26]

It is also reported that globally, the production of cement and steel account for 15% of carbon emissions [26]. Walling materials which are mainly responsible for governing the thermal comfort in buildings constitute another major material responsible for carbon emissions. Therefore, it may be worthwhile to look into the current status of India's cement, concrete, steel and walling materials industries - especially into the sustainability-centric measures taken by these industries in the recent past.

5. Energy-intesntive Building Materials: Current Status

5.1 *Cement*

India happens to be the second largest producer of cement in the world after China. During 2019-20, the Indian cement industry has the installed capacity of 537 million tonnes and the cement production was 334 million tonnes [27].

The long-term growth prediction of the cement industry in India is available from a recent Mckinsey report [28]. The report predicts that cement demand in India will remain in line with GDP growth till 2035, tracking the population growth rate till 2070 and leading to an average annual growth of 2.1 percent over this duration. This could lead to a cement demand of 814 million tonnes per annum by 2070, and a per capita consumption of between 350-370 kg by 2070 from its per-capita consumption of 209 kg in 2019 [28].

It is reported that the Indian cement industry reduced its carbon emissions from 1.12 tonnes/t of cement in 1996 to 0.719 tonne/t of cement in 2010 [29]. Such reduction was attributed mainly to the increased rates of blending of clinker with fly ash and granulated blast-furnace slag (GBS), widespread implementation of waste heat recovery, increased use of alternative fuels, etc.

Two main varieties of cements are used in India - Ordinary Portland Cement (OPC) and blended cements. The latter includes Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC). A recent report by GCCA-India shows that the share of blended cements increased from 30% in 1995 to almost 70% in 2010, Fig 11 [30].

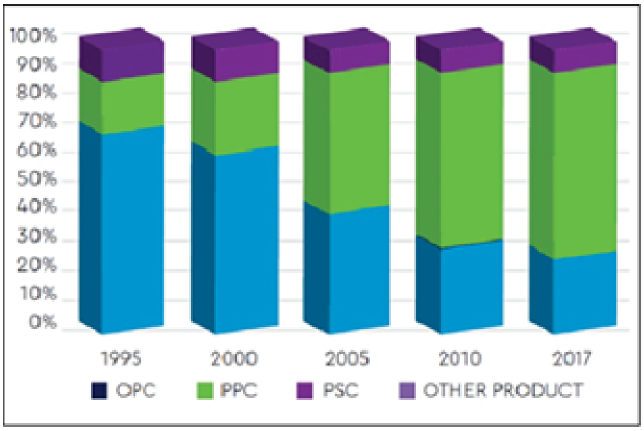

Fig 11 : Share of blended cements dramatically increased from 30% to 70% from 1995-2010 [30]

In 2015, the Bureau of Indian Standard (BIS) published IS 16425 on composite cement, in which the contents of main ingredient vary from 35-65% (clinker), 15-35% (fly ash) and 20-50% (GGBS). The production and use of composite cement has commenced in certain pockets of the country. However, the use of composite cement is not yet permitted in reinforced concrete construction owing to the lack of durability performance data using this cement.

Widespread R&D work has been done globally including India on calcined clay limestone cement (LC^3) which consists of 50% clinker, 30% calcined clay, 15% limestone and 5% gypsum. This cement has the potential to bring down the clinker content by 50%, thus reducing the carbon footprints of cement dramatically. It is expected that LC^3 cement will shortly be available commercially in India.

5.2 *Concrete*

Concrete construction scenario in India has witnessed significant changes since late 1990s. While substantial volume of concrete produced in India is still site-mixed and volume-batched, the demand for higher speed of construction and improved quality necessitated adoption of mechanized and semi-mechanized techniques of construction in metropolitan and other big cities of India, leading to the growth of commercial ready-mixed concrete (RMC) in India. No authentic data is available on the RMC industry in India; however, the unofficial estimate obtained from senior industry personnel reveals that approximately 15-18 % of the cement produced in the country (around 50-60 million tonnes during 2019-20) goes through the batch-plant route - both for commercial and captive use. Using this rough data, the total quantity of concrete produced using modern batch-plant equipment would approximately be 150-180 million m^3 per annum.

One of the major advantages of using RMC is that it provides the flexibility of blending one or more SCMs in concrete, thus reducing the OPC content and carbon footprints. The mixes designed by RMC producers generally contain OPC replacement levels by fly ash up to 30-35% and GGBS up to 50-55%, unless the structural designer specifically demand lower replacement limits. In certain special cases, like mass concrete works, when it is difficult to limit the peak temperature rise to 70ºC and/or temperature differential between the core and surface to 20ºC, some consultants do relax the

OPC replacement level up to 50% or so and agree to change the compressive strength acceptance criteria to be satisfied at 56 day instead of the usual 28 day [31, 32].

The adoption of triple blend cementitious system consisting of OPC+ fly ash (or GGBS) + micro-fine materials like silica fume is found useful for producing high-strength/high-performance concrete - mainly for high-rise buildings and long-span bridges. Since silica fume needs to be procured from abroad, three micro-fine materials have been developed and used indigenously. These include: ultrafine GGBS (IS 16715), high-reactive metakaolin (IS 16354) and ultrafine fly ash (draft version). These materials reportedly have more or less similar performance as that of silica fume in concrete.

5.3 *Steel*

India is the largest producer of sponge iron and the second largest producer of crude steel in the world. Crude steel production grew at 4.2% annually from 103.13 metric tonnes in 2017-18 to 120.29 metric tonnes in 2021-22. The National Steel Policy (NSP) published in 2017 envisages crude steel production capacity of 300 million tonnes per annum by 2030 [33].

A recent McKinsey report makes a long-term projection of the production of crude steel, stating that it is expected to grow seven-fold to reach around 785 metric tonnes per annum by 2070 on the back of rising steel demand driven by India's economic growth [28]. The report also states that the steel sector accounts for about 11 percent of India's total CO_2 emissions and is expected to remain a significant carbon emitter in future.

The report further predicts that the CO_2 emission intensity is likely to reduce from 2 tCO_2/tcs in 2021 to 1.8 tCO_2/tcs by 2040 and then it would fall steeply from 2040 onwards to reach 0.5 tCO_2/tcs by 2070 as green hydrogen-based steel begins to ramp up.

Incidentally, Tata Steel Ltd, one of the leading global steel manufacturing companies, has committed to reduce its CO_2 emission intensity to less than 1.8 tCO_2/tcs by 2030 [34]. The corporate sustainability report of the Steel Authority of India Ltd. (SAIL) points out that the adoption of energy-efficient and CO_2 mitigation technologies by the Company helped in reducing specific energy consumption by 3.7% and specific CO_2 emission by 12.7% in the last ten years. SAIL has fixed up a target of 2.30 tonne of CO_2 emission per ton of crude steel production by 2030 [35].

5.4 *Walling Materials*

Currently, no authentic data is available on the walling market size in India. However, a roughly estimated current walling requirement is believed to be in the range of 200 to 225 billion bricks/annum. A variety of locally-available materials are being used as walling material in different climatic zones in India. While the sun-dried clay bricks have been used in rural India since ancient times, the north-eastern parts of the country have been using abundantly available bamboo (with or without clay/cement-based plaster) in the walling system. For more durable applications, fired clay bricks have been used in the urban areas. The advent of cement and concrete gave an impetus to the use of solid and hollow concrete blocks. In the meantime, as fly ash became available from thermal power plants, the usage of fly ash- based bricks also picked up. As the height of buildings started shooting up in urban areas, the need to reduce the deadload in buildings gave rise to the usage of the lightweight Autoclaved Aerated Concrete (AAC) blocks.

The building envelop consisting of roof, external walls and windows has considerable impact on thermal comfort and hence on the energy use in residential buildings. The Energy Conservation Building Code (ECBC) defines 'Residential Envelope Transmittance Value' (RETV) as the parameter which accounts for heat conduction through external walls/windows. This code specifies that the RETV for the building envelope (except roof) for four climate zones in India, namely, composite, hot-dry, warm-humid, and temperate Climate, shall be less than 15 W/m^2. The thermal resistance (R) and thermal transmission (U) values of the walling materials, which govern the level of thermal comfort in buildings, mainly depend up on the thickness, materials used and its density.

In view of the climate change phenomenon, we have been witnessing steep rise in ambient temperatures, which have been breaking the previous records. For example, India Meteorological Department reported February 2023 was the warmest February month in the past 122 years![36]. Most of India's land mass fall in the hot-dry, warm-humid and composite climatic zones, wherein the major requirement for the buildings is for cooling for a greater part of the year. Hence the choice of the walling material system will become crucial in reducing the energy demand and hence the carbon footprints.

6. Use of Recycled Materials

6.1 C&D Waste

The construction industry in India generates considerable amount of construction and demolition (C&D) waste that includes demolished concrete, returned concrete from RMC plants, bricks, broken steel rods, aluminium, timber, glass, etc. No reliable estimates of the C&D waste generated per annum is available. Also, no data is also available on the currently operational C&D processing facilities. Unofficial data obtained from industry professionals revealed that around dozen of C&D processing facilities have come up in the country. However, it is reported that only 1% of the total C&D waste is recycled; the remaining large chunk goes to landfill [37]. In major cities of India the space for landfill is becoming scarce.

Modern recycling plants are capable of separating different materials from C&D waste. Steel, aluminium, glass, timber, etc can be separated and recycled/reused elsewhere. From the remaining waste, C&D recycling facility can separate out aggregates and powdered materials by recycling demolished concrete. Precast concrete products can then be manufactured from the recycled output and aggregates obtained after recycling can be reused in fresh concrete.

Unfortunately, there is a resistance to use recycled aggregate in concrete as such aggregates have higher water absorption, lower density, lower stiffness and lower abrasion resistance, which adversely affect the fresh and hardened properties of concrete containing recycled concrete aggregates (RCA). Therefore, in spite of the provision in IS 363:2016 specifying the use of RCA in both plain and reinforced concrete for lower grades, with replacement of RCA limited to 20-25% of the natural aggregates, the actual use of RCA in fresh concrete has not picked up in practice.

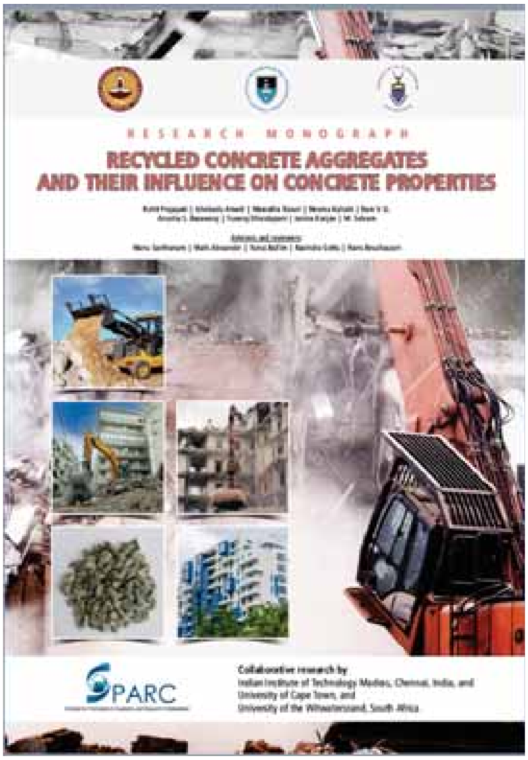

Fig 12 : Research Monograph on Recycled Concrete Aggregates [38]

Fig 13 : Precast concrete products produced from RCA by Godrej [39]

Considerable R&D work has been done on the topic of RCA. A recently published Monograph on RCA under the collaborative research program done by three well-known universities including IIT Madras critically reviewed selected 120-plus technical papers/articles/standards and presented the crux of the findings from the lab and field studies done on RCA, Fig 12, [38]. The Monograph points out that it is the lack of accepted design methods to optimise the quality of RCA and RAC that may have contributed to the apparent shortcomings in the properties of RAC. The Monograph therefore provides useful guidance and advocates the use of performance specifications to achieve the so-called "fit-for-purpose" mix design to produce desirable engineering properties using RCA.

Considering the current and future constraints in the supply of virgin coarse and fine aggregates in major urban areas of India, it is imperative to commence the use of RCA on a large scale. From the consideration of circularity and sustainability aspects, such practice needs to be promoted.

Fig 13 shows a view of some of the precast concrete products produced by Godrej Construction, a unit of Godrej & Boyce manufacturing Company Ltd [39].

6.2 Fly Ash

Fly ash, which is a by-product from thermal power plants, is produced in India on a large scale. According to the recent report of the Central Electricity Authority (CEA), a total of 232.56 million tonnes of fly ash was generated in India during 2020-21 [40]. The construction industry is one of the major users of fly ash - mainly by cement industry, brick and tile industry and the highway sector for the construction of embankments and reclamation of low-lying areas, Fig 14.

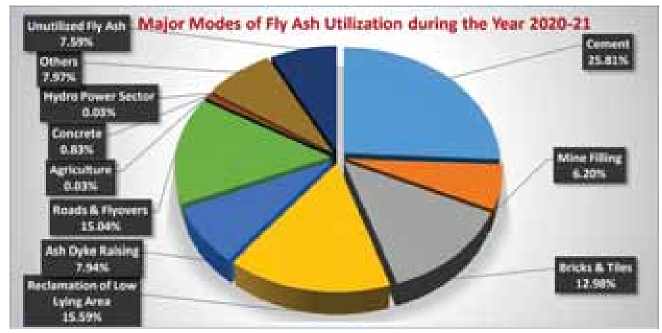

Fig 14 : Major modes of Utilization of fly ash 2020-21 [40]

Earlier, there used to be a large gap in the production and use of fly ash as can be seen from Fig 15. This large gap has now been narrowed down. The CEA report mentioned above shows that 214.9 million tonnes of fly ash was utilized during 2020-21, leaving only 7.59% of fly ash as unutilized.

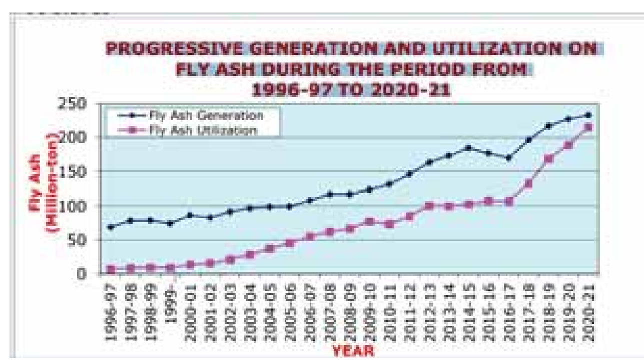

Fig 15 : Generation and Utilization of fly ash during 1996-2021[40]

Of course, there are better ways for utilizing fly ash gainfully, instead using it for mine filling and reclamation of low lying areas. For example, "Nano Concrete Aggregates", developed by the Institute for Solid Waste Research & Ecological Balance (INSWAREB), using 65-75% fly ash and small percentage of cement and other additives could be one such alternative [41]. Fig 16 shows visual

Fig 16 : Natural stone aggregate (extreme left) and 'nano concrete' aggregates (right) [41]

comparison of natural stone aggregate (extreme left) with nano concrete aggregates (right). Such aggregates can be used where acute shortage of coarse aggregates is being felt in certain pockets in the North-East India and in the Indo-Gangetic plains.

6.3 *Recycled Water*

Water is a vital need for human civilization. Adequate amount of clean water is not only essential for the health and wellbeing of the human beings, but it is also imperative for agriculture, industry and energy production.

The per capita availability of water has fallen from 6042 m^3 in 1947 m^3 to 1486 m^3 in 2021- a whopping reduction of almost 75% during the past 75 years [42]. It is expected that the per capita availability of water may further go down to 1140 m^3 by 2051.

The construction industry uses a large quantum of water. Take for example concrete construction, which needs water for performing three important functions. Firstly, water helps in mixing different ingredients of concrete, lubricating the mix and providing the desired workability for placing and compaction. Secondly, water is also required for washing and cleaning of the mixer and other implements, and thirdly for curing of concrete so that concrete achieves desired properties in its hardened state. Currently, no data is available on the quantum of water used by the concrete industry in India. A recent article tries to 'guesstimate' the water requirements for the production of concrete and cement-based products which is placed at around 420 to 500 billion litres per annum[43]. The author suggests that the ready-mixed concrete and precast concrete plants should voluntarily adopt recycling system using a reclaimer and filter press system to recover a part of the water used in the production of concrete and that the same can be reused (see Fig 17).

Fig 17 : Typical reclaimer set-up used in RMC plant for recovery of fine materials and wash water (above) and filter press system capable of delivering clean water and sludge cakes from wash water (bottom)

Incidentally, STP systems are now being installed in large housing complexes in urban areas. Excess amount of grey water from the STPs can be collected and could be used during construction, provided such water satisfies the IS 456 requirements.

6.4 *Water conservation Efforts in Cement and Steel Industries*

The operations of cement and steel - principle building materials required in construction - require large quantity of water. Being conscious of this fact, both industries have been taking utmost efforts to save water through a variety of measures. For example, according to a recent report by GCCA-India, the cement companies in India have adopted a multi-dimensional approach that includes rainwater harvesting, restoring waterbodies, construction of wells and check-dams, converting worked-out mines into waterbodies, promoting low water-intensive crop farming and drip irrigation implementation in and around the communities in which the companies operate, etc. [44]. As a result of the adoption of comprehensive water management strategies, the GCCA report claims that collectively the member companies are four times water positive! This is indeed creditable.

As mentioned earlier, India's National Steel Policy projects a crude steel capacity of 300 million tonnes by 2030-31. The policy also forecasts that by 2030-31, the steel industry will annually require approximately 1500 million m^3 of water [33]. Major steel producers in the country are already taking a variety of initiatives for comprehensive management of their water requirements including recycling, water harvesting and other conservation measures. For example, Tata Steel aims at achieving water neutrality by 2030 [34]. The sustainability report from SAIL states that almost the entire waste water from different plants/units of the company is recycled and re-used [35]. The water conservation initiatives taken by different units of the Company include identification of sources of leakage and plugging of them, setting up of Effluent Treatment Plants (ETPs), assessment and analysis of discharged water from various units to identify areas, where fresh make-up demand can be reduced. The specific water demand of Company has reportedly reduced from 3.44 m^3/tcs in 2018-19 to 3.37 m^3/tcs in 2000-21.

7. Estimations Of Embodied Carbon

The initial efforts of carbon reduction were concentrated on reducing the operational carbon through passive architectural design, improvement in energy efficiency and use of renewable energy. While all such efforts are most welcome, effecting reduction in embodied carbon is a more complex and difficult process. As pointed out earlier, one needs to adopt the life cycle approach to calculate carbon generated during all five stages of the life cycle shown in Fig 5.

Before constructing any new building or a structure, the structural consultant/designer normally considers different alternative designs and ensures that the same satisfy the safety, durability and serviceability criteria. The journey towards achieving net zero carbon now requires that the structural engineer/designer should also calculate the embodied carbons of each alternative design and then choose the one that gives the lowest embodied carbon. Incidentally, nearly 50% of the embodied carbon is generated during the "product" stage i.e. 'cradle to gate' (Fig 5). It would appropriate to concentrate during the initial stage on the product stage for estimating the embodied carbon.

In India, barring few voluntary efforts by selected structural consultants, the practice of evaluating embodied carbon of different alternative designs has unfortunately not yet commenced.

Incidentally, based on the typical concrete mix proportioning data from a commercial RMC plant in Mumbai with which the present author was associated, a rough estimation of the embodied carbon emission of concretes of grades M10 to M50 is estimated and the same is presented graphically in Fig 18. In these mixes, the replacement of OPC by fly ash is limited to 35% and that of granulated

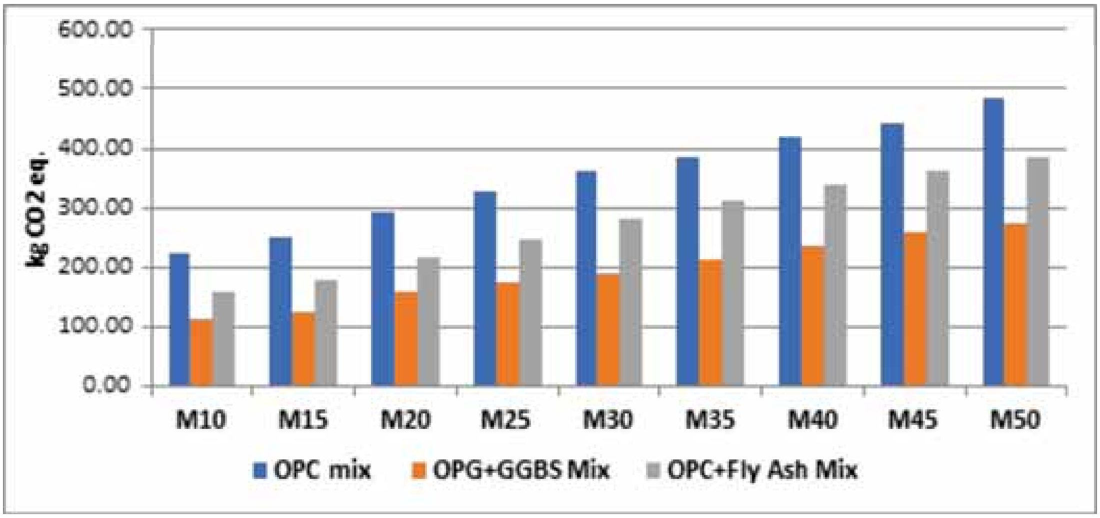

Fig 18 : Embodied carbon emissions of concrete mixes from a typical RMC plant [45]

blast-furnace slag to 50%, following the limits specified in Indian Standards. The embodied carbon emission calculations used the Global Warming Potential (GWP) values obtained from a report prepared by the International Finance Corporation in 2017[45]. It was observed that while the replacement of OPC by fly ash helped in reducing the average embodied carbon emissions by 23.1%, the replacement of OPC by GGBS lowered emissions by 46.14%.

The embodied carbon calculation is based on the accurate estimation of the Global Warming Potential (GWP) of each material or product (measured in kg CO_2e per kg of the material) and multiplying it with the respective quantity of materials.

In India, it will be essential to create indigenous database of reliable GWPs for materials specific to the domestic industry and evolve an institutionalised system and protocol for authentication and upgradation of the same from time to time. The building material manufacturers and their respective trade associations should come forward to undertake such exercise. This needs to be done on utmost priority. It is also suggested that structural engineering companies should calculate the embodied carbon of structures they had constructed in the past and future.

8. Conclusions

Based on the above discussion, following conclusions are drawn.

- Climate Emergency is a stark reality; India is prone to devastating effects of climate change
- India's efforts in increasing the RE capacity manyfold is laudable.
- Buildings and construction sectors account for nearly 40% of CO_2e emission. Decarbonising these sectors is the cost-effective way to mitigate the adverse effects of climate change
- India's building and construction sectors need to supplement the government's efforts and reduce operational carbon from the vast stock of existing and new residential buildings.
- As the majority of India's vast population is reported to be vulnerable to extreme hydro-met disasters, there is an urgent need to undertake steps for adaptation and achieving climate-resilient development.
- While the efforts taken by the Indian cement and steel industries to reduce carbon emissions and welcome, continuing further

efforts in sweeping reduction of carbon are essential.

- There is an urgent need to increase the recycled materials content in construction, including recycled aggregates and recycled water.
- The structural engineering fraternity in India should commence the practice of estimating embodied carbon of different alternative designs of new buildings/structures and encourage clients to choose the one having lowest carbon. The structural engineers also need to create the benchmarks of embodied carbon from the old and new data of structures they designed.
- India needs to create its own depository of GWP of construction materials. For this purpose, the material manufacturers and their respective industry associations need to take the lead.
- The government and the private sector need to make enormous efforts to evolve new low-carbon materials and technologies leading to their use by the industry.

References

1. Intergovernmental Panel on Climate Change (IPCC) "Climate Change :Synthesis Report Summery for Policymakers", 2014, IPCC, Switzerland.
2. Intergovernmental Panel on Climate Change (IPCC) Global Warming of 1.50C Summery for Policy Makers, October 2018, IPCC, Switzerland.
3. William J. Ripple, Christopher Wolf, et al (total 11253 scientists from 153 countries), 'World scientist warning of a climate emergency', View Point, BioScience, Jan 2020, Vol. 70, No. 1.
4. IPCC, Climate Change 2022: Impact, Adaptation and Vulnerability, Summary for Policymakers, Working Group II Contribution to the Sixth Assessment Report, March 2022.
5. IPCC, Climate Change 2022: Mitigation of Climate Change, Summary for Policy Makers, Working Group III, Contribution to the Sixth Assessment Report, April 2022.
6. IPCC, AR6 Synthesis Report: Climate Change 2023, accessed as on march 21, 2023 https://www.ipcc.ch/report/sixth-assessment-report-cycle/
7. International Energy Agency (IEA), CO2 Emission from Fuel Combustion: Overview, Statistics report, July 2020, https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview.
8. Ministry of Environment & Forest, Government of India, India's CHG Emission Profile: Results of Five Climate Modelling Studies, 2009, p. 60.
9. Advancing Net Zero: Asia-Pacific Embodied carbon Primer, World GBC, Sept. 20
10. Climate India 2022: An Assessment of Extreme Weather Events, published by Centre for Science and Environment, 2022, New Delhi,
11. Mohanty A, Wadhwan S., Mapping India's Climate Vulnerability: A District Level Assessment, Council on Energy, Environment and Water, October 2021, p. 78. Source: https://www.ceew.in
12. The road from Paris: India's progress towards its climate pledge, Natural Resources Defence Council, 2020, source: https://www.nrdc.org/sites/default/files/india-progress-climate-pledge-2019-ib.pdf

13. India's Long-Term Low Emission Development Strategy, Ministry of Environment, Forest and Climate Change, submitted to the United Nations Framework Convention on Climate Change (UNFCCC), November 2022.

14. Power Sector at a Glance, Government of India, Ministry of Power, (updated as on December 21st, 2022), https://powermin.gov.in/en/content/power-sector-glance-all-india

15. Ministry of New and Renewable Energy, Government of India, https://mnre.gov.in/

16. Economic Survey 2020-21: Volume 2. Department of Economic Affairs, Ministry of Finance, Government of India.https://www.indiabudget.gov.in/budget202122/economicsurvey/doc/echapter_vol2.pdf

17. CBRE. 2019. Exploring the Future: India at 2030. https://www.cbre.com/insights/articles/exploring-thefuture-india-at-2030.

18. IEA. 2021. India Energy Outlook 2021. International Energy Agency. Paris, France. https://www.iea.org/reports/india-energy-outlook-2021

19. Power Sector at a Glance, Ministry of Power, Government of India, https://powermin.gov.in/en/content/power-sector-glance-all-india (updated 14.03.2023)

20. Ministry of Power, Government of India, Long Term Energy Demand Forecasting, Central Electricity Authority, 2019. p. 149.

21. World Green Building Council, Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon, September 2019.

22. Ministry of Environment, Forest and Climate Change, Press release Nov. 5th, 2020, https://pib.gov.in/PressReleasePage.aspx?PRID=1670351

23. India's RE capacity reaches 168.96 GWas till Feb 2023: Minister R K Singh, https://energy.economictimes.indiatimes.com/news/renewable/indias-renewable-energy-capacity-reaches-168-96-gw-till-feb-2023-minister-r-k-singh/98866975

24. Karthikeyan, S and Dhaka, Shivraj, Advancing Net Zero Energy Buildings in India, LCCF Newsletter, Vol.1, No.2, March-June 2022, pp.1 and 3-5.

25. Orr John, Gibbons Orlando and Arnold Will. A brief guide to calculating embodied carbon', thestructuralengineer.org, July 2020, pp. 22-27.

26. Thomas Czigler, Reiter Sebastian, Schulze Patrick, and Somers Ken. Laying the Foundation for Zero Carbon Cement, Mckinsey & Company, May 2020.

27. Cement Compendium The India Cement Industry - 2019, published by National Council for Cement and Building Materials, December 2019.

28. McKinsey Sustainability 'Decarbonising India : Charting a pathway for sustainable growth', October 2022.

29. Low Carbon Technology for Cement Industry, World Business Council for Sustainable Development - WBCSD, Switzerland, January 2013.

30. Blended Cement: Green, Durable and Sustainable, Report published by Global Cement and Concrete Association (GCCA)-India, Mumbai 2022, p.90.

31. Ashraf, M, Sharma, A, Mokal, M. HVFA concrete for tremie seal and pylon pile cap of Bandra-Worli sea link project, The Indian Concrete Journal, November 2004, pp. 31-36.

32. Kulkarni, Vijay. Use of Fly Ash in Concrete: Current Indian Scenario and a Case Study on HVFAC for Shear Wall Construction in India, EuroCoalAsh 2019 Conference, University of Dundee, June 11-12, 2019.

33. National Steel Policy, 2017, Ministry of Steel, Government of India, https://steel.gov.in/en/national-steel-policy-nsp-2017#:~:text=The%20policy%20projects%20crude%20steel,current%20consumption%20of%2061%20Kgs (as accessed in march 2023)

34. Tata Steel Ltd., Integrated Report and Annual Accounts 2020-21(114th report), Mumbai, www.tatasteel.com

35. Steel Authority of India Ltd. (SAIL), Corporate Sustainability Report 2020-21,

36. 'Warmest February in 122 years', https://www.hindustantimes.com/india-news/warmest-february-in-122-years-101677616755773.html

37. Ram, V. G., Prajapati, R., & Poulose, M. K. (2019). Challenges and prospects of demolition waste recycling in India. Indian Concrete Journal, 9.

38. Research Monograph on Recycled Concrete Aggregates and their Influence on Concrete Properties, Collaborative research by Indian Institute of Technology Madras, Chennai, India, and University of Cape Town, and University of the Witwatersrand, South Africa, Department of Civil Engineering Indian Institute of Technology Madras Chennai, Tamil Nadu - 600036, India.

39. Gawade Abhijeet and Matthew, Anup, Precast Concrete Products from Recycled Aggregates: Noteworthy Example in Sustainability, LCCF Newsletter, Vol 1, No 4., 2021.

40. Central Electricity Authority, Annual Report 2021-22, Ministry of Power, Government of India, https://cea.nic.in/annual-report/?lang=en (as on November 2022)

41. Development of Nano Concrete Aggregates, LCCF Newsletter, Vol. 1, No. 2, 2021, https://www.lccf.org.in.

42. Mohan, Vishwa, What India is doing to tackle its water crises, Times of India, https://timesofindia.indiatimes.com/india/what-india-is-doing-to-tackle-its-water-crisis/articleshow/92141578.cms (updated February 6, 2023)

43. Kulkarni, Vijay, Rough estimation of water requirements for concrete production and measures for conservation, LCCF Newsletter, Vol 1, No. 3, 2021.

44. 'A Tale to Remember: Growing Water Positive', Global Cement and Concrete Association, India Chapter, March 2021.

45. India Construction Materials Database of Embodied Energy and Global Warming Potential: Methodology Report, International Finance Corporation in Partnership with European Union, November 2017. p. 99.