Deterministic Approach for Calculation of Carbon Footprint for Cement Plants in India

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Deterministic approach for calculation of Carbon Footprint for Cement plants in India

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ABSTRACT

Estimating cement process emissions through an industry's dataset has more often if not always been majorly based on strong assumptions. India being the second largest producer of cement across the globe next only to China, lags in providing accurate estimates of its official time-series to UNFCCC (United Nations Framework Convention on Climate Change).

Present study has been undertaken to lay out a deterministic approach for calculation of carbon footprint for any Indian Cement Plant using the customized design methodology. Modelling of which is done by referring to and prioritizing various companies' official data, emission factors, and cement protocols. The framework aligns itself to *Greenhouse Gas Protocol and Cement Sector Emissions Calculation Tool: Indian Version 1.0 (July 2005)* and *CO_2 Accounting and Reporting Standard for the Cement Industry, The Cement CO2 Protocol, Version 2.0 (Cement Sustainability Initiative, June 2005).* It aims to provide a more reliable source for estimation of greenhouse gas - CO_2 emissions in any cement processing plant of India.

Index Terms – CO_2 emissions, Direct & indirect emissions, cement production

I. INTRODUCTION

India is the second-largest cement producer in the world next only to China (Indian Cement Industry Analysis, IBEF, 2021). Accounting for more than 8% of the total installed capacity across the globe (2019), its cement production capacity in FY20 was reported to be about 545 MT (Indian Cement Industry Analysis, IBEF, 2021). The Indian cement industry comprises of 210 cement plants; in a total of which 77 are established in Andhra Pradesh and Tamil Nadu (Indian Cement Industry Analysis, IBEF, 2021). An increase in the installed capacity for cement production is expected to be about 800 MTPA by the year 2030 (Cement, Bureau of Energy Efficiency, 2021). Investment in cement and gypsum attracted US $5.28 billion from April 2000 to March 2020 (DPIIT, IBEF, 2021) and the demand is still high.

Cement production is a major source for greenhouse gas emissions contributing towards CO_2 emissions in majority. According to the Indian Cement Industry report, India's greenhouse gas emission intensity value ranges from 560 kg CO_2/ ton of cement produced to 687 kg CO_2/ ton of cement produced (CII, 2010). Being the largest man–made material in the world, cement is linked relentlessly to Climate Change responsible for health problems and deaths related to air pollution. Economic degradation due to the exponential expense burden in the healthcare department is another consequence. Carbon dioxide is majorly produced as a by-product of clinker production in the process of cement manufacture and as energy produced in fossil fuels. However, the dependence on meeting the global economic productions through energy from combustion of fossil has detritus effects expected to harm global welfare and diminish economic productivity.

II. LITERATURE REVIEW

The industrial and energy sources in cement production contribute to approximately 2.4% of the global carbon dioxide emissions (Marland et al., 1989). As per estimations, 0.5 to 0.9 kg of CO_2 is emitted on the production of 1 kg of cement (Gartner, 2004). 90% of the energy required for cement manufacturing is met out of fossil fuels while the remaining 10% is met whence electricity. (C. A. Hendriks et. al., 2004). Besides, E. Benhelal et al., (2013) reasoned out the estimation of global CO_2 emissions from the cement industry at 5% to Portland cement manufacturing and the use of outdated industrial equipment responsible for the consumption and the consequent evolution of huge amounts of particulate matter. And even though the latest technologies have increased the production efficiency of cement production, there has been a significant rise in CO_2 emissions as a consequence of increased demand for development in infrastructure. (G. U. Fayomi et al., 2019).

Cement Processing in a Plant

Cement is a binding material used for construction to bind the materials together. It is generally used to bind sand and gravel together to manufacture concrete and with fine aggregates to manufacture mortar or masonry. Every cement plant undergoes the steps shown in Fig. 1 for the manufacturing of cement.

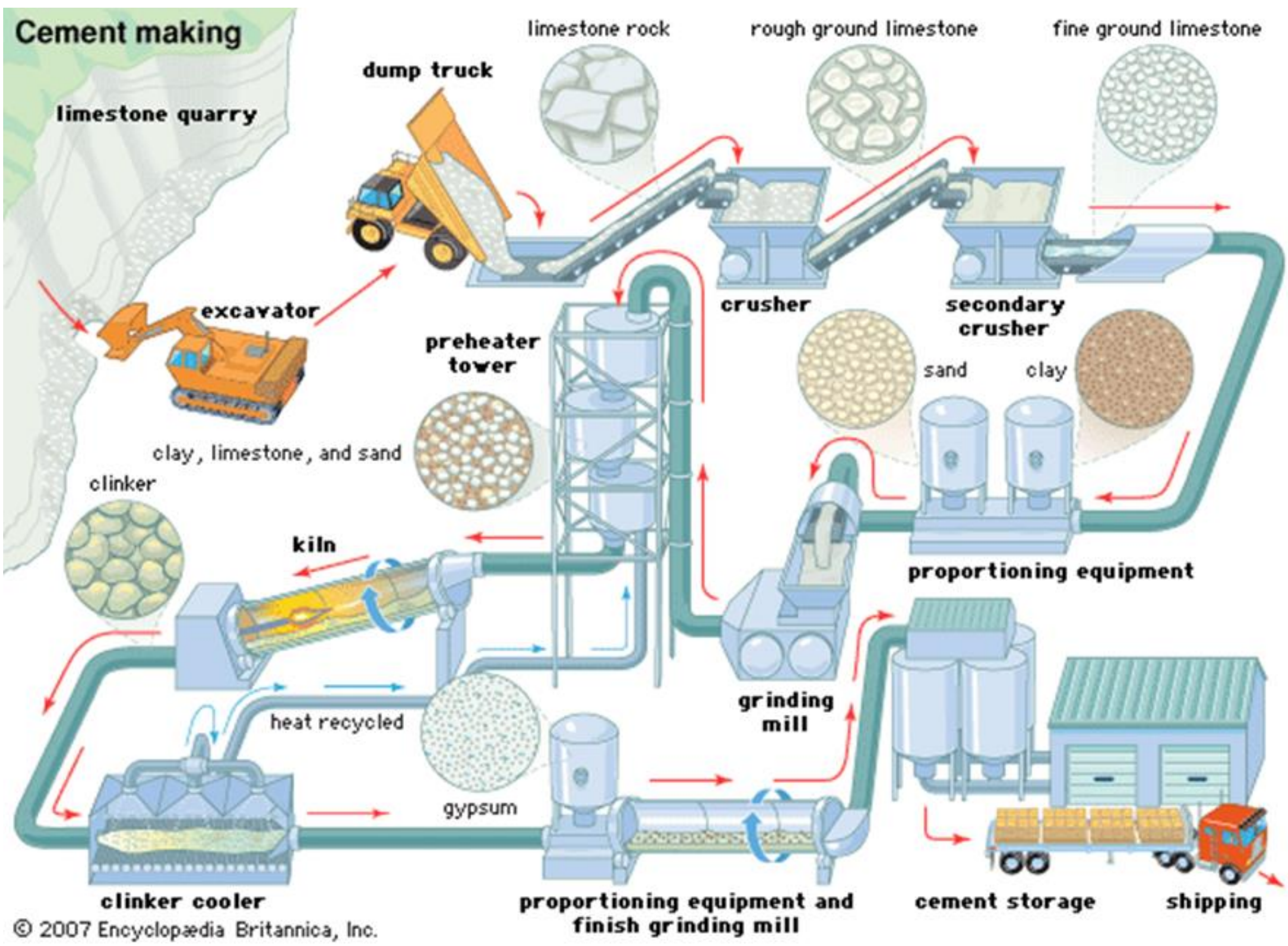

Fig. 1 – Cement manufacturing processes in a cement plant

(Encyclopedia Britannica, Inc., 2007)

Carbon capture in Cement manufacturing plant

The reaction begins at the limestone quarry. The limestone near the surface has a high content of minerals like silica, iron and aluminum oxide. On – going at a further depth, we find more of $CaCO_3$ content. The first carbon footprint counts or carbon capture is marked here; in making a big hole using machines which take up a lot of energy. Limestone found in mines are then drilled to smaller sizes in the process of quarrying.

Next, the detonator is fixed and the holes are digged in the ground and plant-powerful explosives are set - up for blasting. (Maintaining a distance of at least 50m). Here, the second carbon capture is observed. For emissions from blasting which include CH_4 and CO_2 emissions from natural gas extraction, CO_2 emissions from ammonia production and the emissions from the actual blasting.

After blasting, the material is filled in the dumper using an excavator which is weighed at the cement plant to determine the amount of raw material for the plant. After the explosion the loaders move in, they transfer the limestone rock to a dump truck. At the plants, the trucks, dump the rocks in the primary crusher. The primary crusher reduces the material to smaller sizes. There is a constant spray of water to keep the dust from billowing up and settling on the shoots. This conversion also gives out a lot of energy marking as the third carbon capture.

Next, the limestone is fed in the crusher which is sent to the compound impact cursor using a conveyor. The material is crushed using limestone crusher to finer sizes (25 mm or 30 mm) depending upon the available mill as vertical roller mill or ball mill. Rocks with high calcium carbonate and rocks low in calcium carbonate are crushed separately. Then it's mixed. This overhead machine also known as the tripper then makes piles of the required proportions known as the raw mix. A reclaimer loads this raw mix into a grinding machine called a roller mill. The factory or plant adds extra minerals such as silica and iron. Certain types of cement also require aluminum oxide. The roller then mixes and grinds the ingredients uniformly producing a dry rock powder called the raw meal. More crushing implies more energy and all the added minerals have their own associated emissions thereby marking the fourth carbon capture.

Now the powder goes into the pre-heater, the temperature of which is 80˚C upon entering. Within 40 seconds it gets more than ten times hotter, releasing a lot of energy responsible for fifth carbon capture in the plant. This begins the process of bonding the minerals together so that they later harden when hydrated with water.

The preheater is equipped with a flash calcine. In about 5s it removes about 95% of the CO_2 and the powder through a chemical reaction isolates the lime which is the most important element in the cement. In 5s, 95% of the fixed CO_2 is released in the atmosphere which had been stripped from the limestone fixed in the rock for over 100 million years, polluting it and marking the sixth carbon capture.

From here the powder moves into the rotary kiln which is a huge cylindrical furnace. It is set at an angle so that the powder moves a distance of about 49 m from top to bottom. The kiln rotates about two turns a minute to ensure the material travels through at a right speed. The burner gas flame at the bottom reaches a scorching 1600˚C – 1700˚C. As the powder approaches or cools down to a 1500˚C mark, it fuses into pieces with a diameter of about 5 cm approximately. These pieces are called clinkers. As the clinker leaves the kiln, large fans further cool it down to a temperature range of 60˚C – 80˚C. It is important to cool the clinker quickly in order to have quality cement. According to IPCC (Intergovernmental Panel on Climate Change, 2008) every 1 ton of clinker releases 1.25 tons of CO_2 in the atmosphere. Thereby making this stage as the eighth carbon capture.

From here, the clinker goes to the storage area. This process requires tons of fossil fuels to release CO_2 from clinkers marking the seventh carbon capture. This also explains the reason behind cement plants produce more CO_2 emissions than cement.

The last stage of cement processing is finish grinding. In this stage, gypsum is added to the clinker. Gypsum delays the cement's initial setting time so that it can be worked for up to 2 hours before hardening. The material after being crushed is transported using a conveyor belt to the pile yard for stocking. Here, the material is homogenized using the reclaimer and scraping chain along the belt conveyor. This is the final and the eighth carbon capture concluding the cement manufacturing, transporting and storing process in the plant in complete totality.

III. OBJECTIVE

This study has been intricately performed to overcome the problem of data unavailability for calculating CO_2 emissions in the processing of cement in India. It has been resolved by factually analyzing the various cement – manufacturing industries' official data, emission factors, and cement protocols with reduced assumptions for better accuracy. As a consequence, a customized framework has been designed with the aid of *Greenhouse Gas Protocol and Cement Sector Emissions Calculation Tool: Indian Version 1.0 (July 2005)* and *CO_2 Accounting and Reporting Standard for the Cement Industry, The Cement CO_2 Protocol, Version 2.0 (Cement Sustainability Initiative, June 2005).* The framework has been broadly classified into Scope 1 and Scope 2 for calculation of direct CO_2 emissions and indirect CO_2 emissions respectively in various cement-manufacturing plant units. It is a user-friendly algorithm that may be utilized as a guide for computation of the carbon footprint of Indian cement plant(s). This can be done by performing certain alterations throughout the framework after the assembling of scrutinized plant-specified data.

IV. METHODOLOGY

The framework generated in this paper is compatible with the latest guidelines for national greenhouse gas inventories issued by IPCC (Intergovernmental Panel on Climate Change) and with the revised WRI / WBCSD Protocol. The framework has been developed with the aid of *Greenhouse Gas Protocol and Cement Sector Emissions Calculation Tool: Indian Version 1.0 (July 2005)*, an algorithm developed by the World Resource Institute (WRI) also called as the *Indian Cement tool* and *CO_2 Accounting and Reporting Standard for the Cement Industry, The Cement CO_2 Protocol, Version 2.0 (Cement Sustainability Initiative, June 2005)* which is intended as a tool for cement companies worldwide inclusive of calculations for direct and indirect CO_2 emissions. The companies undertaken must include activities such as clinker production, including raw material quarrying, grinding of clinker, additives, and cement substitutes such as slag, both in integrated cement plants and stand-alone grinding stations in the voluntary calculation using this framework. The framework is ideal for calculating the carbon footprint of any Indian cement plant/industry and may be used for further investigation or exploration in the same field.

Framework

The framework breaks down the scope of calculating CO_2 emissions into Scope 1 and Scope 2 based on direct CO_2 emissions and indirect CO_2 emissions from cement processing in the industry respectively.

Scope 1 – Direct CO_2 emissions

Direct CO_2 emissions are those that are generated from sources owned or controlled by the cement – producing companies. These emissions are primarily a result of CO_2 emissions attributed to the calcination of raw materials and fuel combustion. Calcination is the process of transforming raw materials into clinker. And, fuel combustion is the process of burning the fuels (oil, coal, petrol coke, etc.) in kilns and mobile combustions. Also, the scope takes into consideration emissions from the organization's vehicles and (if any) refrigerant – leaks on site. In short, all on-site emissions are accounted for in Scope 1. The in-depth discussion regarding these sources and their calculations has been done and performed in the coming sections subcategorized into –

- Scope 1.1 – CO_2 from raw materials
- Scope 1.2 – CO_2 from direct stationary combustion
- Scope 1.3 – CO_2 from mobile combustion

Scope 1.1 – Calculating CO_2 emissions from raw material

The emissions from scope 1.1 originate from the calcination of clinker, calcination of dust, and organic carbon in the raw material. Calcination is defined as the purification process of heating (oxidizing) the raw materials at a high temperature to remove the volatile materials from the mass. Cement process CO_2 emissions mainly from calcination of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) in the raw meal for clinker production, which can be expressed by the following chemical equations (Worrell et al., 2001).

$$CaCO_3 \rightarrow CaO + CO_2 \quad (1)$$

$$MgCO_3 \rightarrow MgO + CO_2 \quad (2)$$

Using the relative formula mass M_r, the above chemical equations can be rewritten accordingly to the suit the law of conservation of matter.

$$M_r\,(CaCO_3) = M_r\,(CaO) + M_r\,(CO_2) \quad (3)$$

$$M_r\,(MgCO_3) = M_r\,(MgO) + M_r\,(CO_2) \quad (4)$$

Where, M_r is the molar mass

$M_r\,(CaCO_3)$ =100.09 u

$M_r\,(MgCO_3)$ = 84.31 u

$M_r\,(CaO)$ = 56.08 $M_r\,(MgO)$ = 40.30 u

M_r (CO2) = 44.01 u

From the above equations, it is observed that the calcination of 1 ton (t) of $CaCO_3$ emits about 0.44 t of CO_2, and the calcination of 1 t of $MgCO_3$ emits about 0.52 t of CO_2.

Generally, there are two types of widely – accepted and often – used calculation methods for estimating the processed CO_2 emissions from cement production: the input method (raw materials or raw meal in particular) and the output method (clinker method and cement method) (CSI, 2011). In this framework, the output methods have been included which are the Clinker – based approach and Cement-based approach. Either of the two methods may be used depending upon the availability of data from the company for calculating direct CO_2 emissions from raw materials.

The framework is designed for **the annual production of Ordinary Portland Cement (OPC) in cement manufacturing companies**. The **amount of Cement produced is assumed to be 1 ton**. This standard value can be multiplied with the data from the cement company and consecutive changes may be made throughout the framework for calculation purposes. Besides, alteration may be done to the framework for different types of cement, plant-specific values for emissions, and much more. For reference, the framework is inclusive of certain parameters intricately yet sequentially mentioned throughout the framework.

Considering the average CO_2 emission factor for clinker (EF_{Cli}) equal to 0.528 t CO_2 / t clinker (Indian Cement tool, [6]), on an average the production of 1 ton of cement releases 1.25 tons of CO_2 (IPCCC, 2018).

- 1 tons of cement → 1.25 tons of CO_2
- 1 ton of clinker (releases) → 528 kg of CO_2 = 0.528 tons of CO_2

From the above equations,

- 1 ton of CO_2 is released from → (1/ 0.528) tons of clinker
- 1 ton of CO_2 is released from → 1.893 tons of clinker
- 1.25 ton of CO_2 is released from → 1.893 x 1.25 tons of clinker

1 tons of cement → 2.36 tons of clinker → 1.25 ton of CO2 (5)

Therefore, average amount of clinker produced for 1 ton of cement production = 2.36 tons.

(I) <u>Clinker – based approach</u>

This approach calculates CO_2 emissions from cement production based on the CaO and MgO content and the amount of clinker thereby produced. This method involves estimating process-related CO_2 emissions from cement production.

Step 1: Consider the amount of clinker produced (P_{Cli}) = 2.36 tons (assumption, from eq. (5))

Step 2: Average CO_2 emission factor for clinker (EF_{Cli}) = 0.528 t CO_2 / t clinker (Indian Cement tool, [6])

Step 3: The amount of CKD lost in the absence of plant – specific value may be considered as 2% of CO_2 released

from clinker production. (from eq. (5), CSI, [7])

Therefore, the amount of CKD lost = (0.02) x (1.25) = 0.025 tons

Step 4: Average CO_2 emission factor for CKD (EF_{CKD}) = 0.4514 t CO2 / t CKD lost (Indian Cement tool, [6])

Step 5: Let the total CO_2 emissions from Scope 1.1 be X_1. (Indian Cement tool. [6])

$$\text{(Total } CO_2 \text{ emissions from scope 1.1)} = P_{Cli} \cdot EF_{Cli} + CKD \cdot EF_{CKD} \quad (5)$$

$$X_1 = 2.36 \text{ x } 0.528 + 0.025 \text{ x } 0.4514 = 1.257 \; CO_2$$

Let CO_2 emissions per ton of raw material (clinker) used be A

A = 1.257 / 2.36 = 0.5327 t CO_2

In the absence of plant – specific value, the value of A shall be directly multiplied with the amount of clinker produced (in tons). In which case, the intermediate steps may be skipped. However, one should ensure that when doing so the assumptions mentioned in the beginning of the framework are matched.

(I) <u>Cement – based approach</u>

Since different types of cement contain varying clinker fractions, it is important to segregate cement production data by its cement type. In the cement-based approach, the data should be reported separately for Ordinary Portland Cement (OPC), Pozzolana Portland Cement (PPC), Portland Slag Cement (PSC), and other cement types. Some of the default clinker fractions based on the assumed cement type blends can be used as given in Table 1 (Indian Cement Tool, [6]). This method involves estimating process-related CO_2 emissions from cement production.

Table 1: Default clinker to cement ratio based on cement type

S. No.	Cement Type	Clinker to cement ratio (%)
01	Ordinary Portland cement (100% Portland output)	95
02	Portland Pozzolana Cement	75
03	Portland Slag Cement	55

Step 1: Consider the amount of cement produced = 1 ton (assumption, eq. (5))

Step 2: Clinker to cement ratio = 0.95 (OPC, Table 1)

Step 3: Total clinker that is released from just the cement production may be calculated as-

(Total clinker from cement production only) = (amount of cement produced) x (clinker to cement (6) ratio)

= 1 x 0.95 = 0.95 tons of clinker (Indian Cement tool, [6])

Step 4: Consider he amount of clinker imported and exported. Assuming that no clinker has been imported or exported to the plant. Therefore, amount of clinker imported and exported = 0.

Step 5: Total clinker produced in the company / facility / plant is calculated as below. (Indian Cement tool, [6])

= (Total clinker from cement production) – (imported clinker) + (exported clinker) (8)

= 0.95 tons of clinker

Step 6: To determine the amount of raw materials used and then calculate ton of raw material per ton of clinker on dividing. In the absence of plant – specific value for raw material or import and export clinker amounts, the default value of 1.5 can be considered.

Therefore, (t of Raw material) / (t of Clinker) = 1.5 (Indian cement tool, [6])

Step 7: To determine the amount of $CaCO_3$ equivalent used to produce clinker, calculated as –

($CaCO_3$ equivalent raw material ratio, %) = ($CaCO_3$ equivalent for raw material) x (amount of raw material)

In the absence of plant – specific value, consider the default value of $CaCO_3$ equivalent raw material ratio as 0.78. (India Cement Tool, [6])

Step 8: Finally, let the total CO_2 emissions (in tons) be X_1'

$X_1' = P_{cement}$ x (clinker/cement) x (RM/clinker) x ($CaCO_3$ equivalent/ RM) x (MW CO_2/MW $CaCO_3$) (9)

where RM = Raw Material and MW = Molecular Weight (Indian cement tool, [6])

The stoichiometric ratio of CO_2 to $CaCO_3$ = (44/100) = 0.44

= 1 x 0.95 x 1.5 x 0.78 x 0.44

= 0.489 tons of CO_2 emissions

Let the CO_2 emissions per ton of raw material (cement) used be B.

Then, B = 0.489 kg CO_2 / ton

In the absence of plant – specific value, the value of B shall be directly multiplied with the amount of cement produced (in tons). In which case, the intermediate steps may be skipped. However, one should ensure that when doing so the assumptions mentioned in the beginning of the framework are matched.

Scope 1.2 – Calculating CO_2 emissions from direct combustion

When the raw material is fed into the preheater rotary kiln, the conventional kiln fuels like anthracite, bituminous, and coke, alternative fossil fuels like natural gas, biomass fuels, non – kiln fuels like NO_X, and wastewater in combusted; all of which come under scope 1.2. In this scope, the steps represented in Table 2 below are used to calculate CO_2 emissions from each fuel.

Table 2: Step – by – step procedure for calculation of scope 1.2 CO_2 emissions

S. No.	Fuel	Quantity of fuel burned (in tons) (I)	Calorific value of fuel (in GL/ tons) (II)	CO_2 Combustion Factor (in kg CO_2/ GJ) (III)	Oxidized carbon fraction (IV)	Total CO_2 emissions from fuel (in kg) (= I x II x III x IV)
Eg	Bamboo Dust	45000	15.25	96.10	1.00	66,948,625

Σ = ………..

The above table for individual fuel calculations has also been represented in steps below. The total CO_2 emissions contributing towards scope 1.2 is the summation of CO2 emissions from each fuel. (Indian Cement tool, [6])

Step 1: Consider the quantity of fuel burned (in tons)

Step 2: Average net calorific value in GL/ tons (plant – specific/ default value)

Step 3: Calculate quantity of fuel used in energy (in GJ) (using the formula) (Indian Cement tool, [6])

Quantity of fuel used in energy = (Quantity of fuel burned) x (Average net calorific value) (10)

Step 4: Take CO_2 combustion emission factor specific to fuel (kg CO_2/ GJ) (plant – specific/ default value)

Step 5: Consider the oxidized carbon fraction. In case of unavailability of this value, certain default values are given below.

Table 3: Default value for oxidized carbon fraction based on fuel type

S. No.	Fuel type	Oxidized carbon fraction
01	Coal/ Lignite used in kiln of pre – calcinator	1.00
02	Coal used in other furnaces	0.98
03	Oil	0.99
04	Gas	0.995

(Reference – Indian Cement tool)

Step 6: Therefore, CO_2 emissions (in kg) (Indian Cement tool, [6])

= (Quantity of fuel used in energy) x (CO_2 combustion emission factor) x (oxidized carbon fraction) (11)

= ……… kg CO_2 emissions = …….. tons CO_2 emissions

The summation of CO_2 emissions from each fuel type contributes towards the total CO_2 emission in Scope 1.2. Let X2 be the total CO_2 emissions from Scope 1.2. Therefore, $X_2 = \Sigma$ (fuel emissions, tons).

Scope 1.3 Calculating CO_2 emissions from direct mobile combustion

In this framework, we have only considered the transportations wherein the vehicles are owned or controlled by the reporting entity or the company under consideration. The cement production process involves the transportation of raw materials, fuels, and the distribution of finished goods. The transportation modes can be railways, waterways, and/or roadways; each of which emits CO_2 which is accounted for under this scope. The following diagram highlights the inclusivity of Direct and Indirect emissions from the on-site emissions from transportation in the framework.

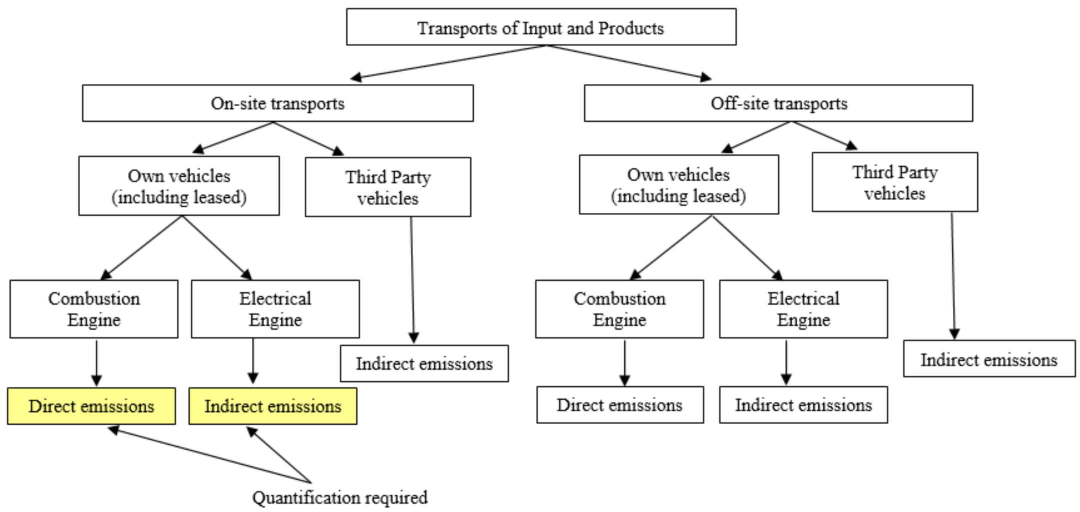

Fig. 2 Breakdown of transports by type, and coverage (Indian Cement tool)

Table 4 also latter represented in steps are used to calculate the CO_2 emissions for each vehicle and its corresponding fuel type. These steps are repeated for each vehicle type and the results for each cycle are added. The summation of the final CO_2 emissions for each vehicle type results in the total CO_2 emissions contributing towards Scope 1.3. This can be calculated either using distance travelled by the vehicle or through its fuel consumption details.

Method 1: CO2 emissions from fuel consumption in the vehicle(s)

When fuel consumption data for a vehicle is available (Plant-specific values)

Table 4: Step – by – step procedure for calculation of scope 1.3 – METHOD 1 CO_2 emissions

S. No.	Transport Description	Fuel type Used	Fuel consumption Or quantity of fuel Burned (L) (I)	CO_2 emission Factor (in kg CO_2 / L) (II)	Oxidized carbon fraction (default value) (III)	Total CO_2 emissions (tons) =(I x II x III)/ 1000
E.g.	Loader	Diesel	5000	0.1005	**0.99**	502.5

Σ = …………

Step 1: Collect data regarding the vehicle type, fuel used, its fuel consumption, CO2 emissions factor for the fuel type in vehicle type.

Step 2: Taking default value of oxidized carbon fraction as **0.99** (Indian Cement tool, [6])

Step 3: Let the total CO_2 emissions (in tons) be X_3, then using the formula – (Indian Cement tool, [6])

$$X_3 = (\text{Fuel consumption}) \times (CO_2 \text{ emission factor}) \times (\text{oxidized carbon fraction}) / 1000 \quad (12)$$

Method 2: CO_2 emissions from distance – travelled by the vehicle(s)

Table 5: Step – by – step procedure for calculation of scope 1.3 – METHOD 2 CO_2 emissions

S. No.	Transport Description	Distance travelled On-site (km) (I)	CO_2 emission Factor (in kg CO_2 / km) (II)	Total emissions (in kg) (= I x II)
E.g.	Loader	5000	0.1005	502.5

Σ = …………

Step 1: Collect the data regarding the vehicle and fuel type, quantity of such vehicle types like trucks, cars, dumpers, loaders, and more visiting the site per day, the average distance travelled by it on – site in a year, and the specific CO_2 emission factor corresponding to the vehicle and fuel type.

Step 2: The total CO_2 emissions from mobile combustion of each vehicle is calculated as below. (Indian Cement tool, [6])

Total CO_2 emissions from mobile combustion = (Distance travelled) x (CO_2 emission factor) (13)

= ……… kg = ………. tons

Let total CO_2 emissions from scope 1.3 emissions be X_3.

Therefore, $X_3 = \Sigma$ (emissions from each vehicle type)

Total CO_2 emissions from SCOPE 1

Let total CO_2 emissions from scope 1.1, 1.2 and 1.3 will be X.

Thus, $X = X_1 / X_1' + X_2 + X_3$

Scope 2 – Indirect CO_2 emissions

An organization may use energy that doesn't generate emissions onsite. However, the creation of electricity and its distribution results in emissions that are off-site (from the power plant). It should be noted that electricity emissions vary greatly because of the fuel used to produce electricity. For e.g., Coal produces the most – emissions because it is not a clean fuel. Electricity can also be generated from heavy furnaces, oil, or gas which are relatively cleaner. The cleanest source of electricity is renewables.

Table 6 also latter represented in step below can be used for calculating the contribution of CO_2 emissions for each stream description. The total CO_2 emissions contributing towards scope 2 will be the summation of all CO2 emissions from electricity consumption (Σ).

Table 6: Step – by – step procedure for calculation of scope 2 CO_2 emissions

S. No.	Description	Electricity Purchased (in kWh) (I)	CO_2 emissions Factor (in g CO_2/ kWh) (II)	Indirect CO_2 Emissions (in tons) (= I x II)
E.g.	--	80000000	806	64480

Step 1: Consider the emission factor based on the location of the industry (Indian Cement tool. [6])

Step 2: Take average electricity purchased in kWh for a year (plant – specific value)

Step 3: Therefore, CO_2 emissions from each electricity consumption activity is calculated as below. (14)

CO_2 emissions from each electricity consumption = ((Electricity purchased) x (CO_2 emission factor))/ 1000000

= ……………. Tons (Indian Cement tool, [6])

Let the total CO_2 emissions from scope 2 be Y

Then, $Y = \Sigma$ (CO_2 emissions from each electricity consumption activity)

Calculating total carbon footprint

Calculating carbon footprint = CO_2 emissions produced by the industry in a year = (X+Y)

= ……….. tons per annum

V. CASE STUDY

To substantiate the credibility of this framework, let's calculate the CO_2 emissions for the following case study of one of the leading cement-manufacturing companies in India. The results of which would later be tallied with the actual reporting data/ figures acquired from their official websites. For simple yet efficient processing of the entire framework which is easy to understand, certain assumptions would be made in the progression.

Assuming the company's name is ABC.

Background of company ABC – one of the leading cement-manufacturing companies in India

ABC company has its roots all across India with 17 cement manufacturing units, 90 ready – mix concrete plants with over 6600 employees and vast distribution network of 50,000 + dealers. The cement type manufactured in ABC is Ordinary Portland Cement (grade 53 and grade 43) in the bag size of 50 kg. The CO_2 emissions calculated for the inputted data for the year 2018.

For Scope 1.1 – CO_2 emissions from raw materials (Using Cement – based approach)

Due to the unavailability of the clinker data for the company, the cement – based approach has been opted for calculating CO_2 emissions from raw materials.

Step 1: Total amount of cement – produced = 33.05 MT (installed cement capacity, Sustainability Report, 2019)

Step 2: Clinker to cement ratio = 95% (Indian Cement tool, [16])

Step 3: Therefore, the clinker used for the cement production (in tons) using formula –

(Total clinker used for cement production) = (cement produced) x (clinker to cement ratio)

= (33.05) x (-0.95) = 31.395 tons' clinker

Step 4: Imported clinker and exported clinker = 0 (no data available)

Step 5: Therefore, total clinker produced in the facility/plant

= (total clinker used for cement production) -(imported clinker) + (exported clinker)

Step 6: The raw materials and their amounts used are listed as below. (ABC Sustainability Report)

Table 7: Quantity of raw materials used for manufacturing of OPC cement in ABC company

S. No.	Raw material	Quantity (in MT)
01	Limestone	24.86
02	Gypsum	1.18
03	Alternate materials	3.37
04	Slag	3.18
05	Fly ash	5.74
06	Additives	0.10
07	Others	1.67

Σ = 37.1 MT

Other raw materials like lubricating oil, grease are proportionately very small and hence neglected for calculations.

Therefore, the amount of raw materials used for manufacturing of cement = 37.1 MT

Step 7: The amount of $CaCO_3$ used to produce clinker

= ($CaCO_3$ equivalent / raw material) x (amount of raw material)

The default value of ratio of $CaCO_3$ to raw material is considered, since the plant-specific value is not available. Implying, ($CaCO_3$ equivalent / raw material) = 0.78. (Indian Cement tool [16])

(Amount of $CaCO_3$ used to produce clinker) = (0.78) x (37.1) = 28.93 MT CaCO3

Step 8: Finally, the total CO_2 emissions (in tons) is given by the formula -

= P_{cement} x (clinker/cement) x (RM/clinker) x ($CaCO_3$ equivalent/ RM) x (MW of CO_2/ MW of CaCO3)

= (33.05) x (0.95) x (37.1/31.395) x (28.93/37.1) x (44/100) x 10^{-6} MT CO_2 emissions

= 12.5 MT CO_2 /

Therefore, X_1' = 12.5 MT CO_2

For Scope 1.2 – CO_2 emissions from direct stationary combustion (fuel combustion)

Combustion of the kiln (conventional and alternative), and non – kiln fuels for ABC and their respective energy consumptions have been listed in Table 8 and Table 9 respectively. The individual values of the quantity of fuel used, their calorific values, and the oxidized fraction are not available. However, the data for the energy consumption by each fuel is available. It can be expressed as below.

Energy consumption = (Quantity of fuel burned) x (calorific value of fuel) x (oxidized carbon fraction) (15)

Now using the framework, and representing the steps for calculations under scope 1.2 in tabular form under Table 8 and Table 9 with a combined column for Energy consumption.

1. **CO_2 released from conventional and alternative kiln fuels**

The kiln fuels used by the company are listed as below.

Table 8: Step – by – step procedure for calculation of ABC CO_2 emissions from kiln fuels

S. No	Fuel	Energy consumed (in TJ)	Energy consumed (in GJ) x 10^3 (I)	CO_2 combustion factor ($kgCO_2/GJ$) (II)	COLUMN A Total CO_2 emissions (kg) = (I) x (II)
1.	Pet coke + coal	51,417	51417000	107.738	5539564746
2.	Diesel oil	62	62000	73.84	4578080

3.	Biomass fuels	648	648000	69.98	45347040
4	Alternative fuels	1,744	1744000	112.45	196112800

CO_2 released from conventional and alternative fuels = Σ (COLUMN A) = 578560266 kg = 5.785 MT CO_2

2. **CO_2 released from non - kiln fuels**

The non - kiln fuels used by the company are listed as below.

Table 9: Step – by – step procedure for calculation of ABC CO_2 emissions from non-kiln fuels

S. No	Fuel	Energy consumed (TJ)	Energy consumed (in GJ) x 10^3 (I)	CO_2 combustion factor (kgCO$_2$/GJ) (II)	COLUMN B Total CO_2 emissions (kg) = (I) x (II)
1.	Pet coke + coal	24,510	24510000	107.738	2640658380
2.	Diesel oil	7	7000	73.84	516880
3.	Biomass fuels	100	100000	69.98	6998000
4	Alternative fuels	167	167000	112.45	18779150

CO_2 released from non – kiln fuels = Σ (COLUMN B) = 2666952410 kg = 2.667 MT CO_2

Thus, the total CO_2 emissions from scope 1.2 (X_2) = Σ (COLUMN A + COLUMN B) = 5.785 + 2.667

Therefore, X_2 = 8.452 MT CO_2

For Scope 1.3 – CO_2 emissions from direct mobile combustion

Major contribution towards production of CO_2 emissions in the company/ industry has been from the truck. Assuming the truck to be of an average weight of 16 tons with 4 km per liter mileage. (Assumptions, [11])

Using Method 2 – CO_2 emissions from distance travelled by the vehicle

Here, the truck with diesel is travelling on – site which is responsible for CO2 emissions based on distance travelled on-site. The default value for diesel is taken to be 74.01 kg CO2/ GJ (Indian Cement tool, [6])

By stoichiometry,

- 1 GJ energy of diesel (generates) → 74.01 kg of CO_2
- Fuel energy density of diesel = 38.6 MJ/L (Fuel energy density,[13])
- 1 L of diesel (releases) → 38.6 MJ energy
- 1 L of diesel (releases) → 0.0386 GJ energy (1 GJ = 1000 MJ)
- 25.9 L of diesel (releases) → 1 GJ of energy

Therefore, on equating (1) and (2)

- 25.9 L of diesel (generates) → 74.01 kg of CO_2
- 1 L of diesel (generates) → 2.857 kg of CO_2

Since, the truck weighs an average of 16 tons with 4 km per liter mileage

Therefore, in 1 L, the truck travels 4 km (roughly)

Which implies that, 2.857 kg of CO_2 is released when the truck travels 4 km.

That is, 0.71425 kg of CO_2 is released when the truck travels 1 km.

Thus, the CO_2 emission factor (in kg CO_2/ km) = 0.7145

Table 10: Step – by – step procedure for calculation of ABC scope 1.3 – METHOD 2 CO_2 emissions

S. No.	Transport Description	Fuel type used	Distance travelled On-site (km) (I)	CO_2 emission Factor (in kg CO_2 / km) (II)	Total emissions (in kg) (= I x II)
01	Truck	Diesel	7904157584	0.7145	5645544554

Therefore, X_3' = 5.6455 MT CO_2

Total CO_2 emissions from scope 1 is X = $X_1 + X_2 + X_3$ = 12.5 + 8.452 + 5.645 = 26.59 MT ≈ 26.6 MT

SCOPE 2: Calculating CO_2 emissions due to indirect air emissions

Average of emission factors = .806 kg CO_2/Kwh (Indian Cement tool, [6])

Total electricity consumed = 6,01,649,000Kwh (ABC Sustainability Report 2019)

Total CO_2 released due to indirect air emissions = (Electricity emission factor) * (total electricity consumed)

Total emissions = (6,01,649,000) x (.806) = 484929094 kg CO_2 = 0.484929094 MT CO_2

Tabulated as below.

Table 11: Step – by – step procedure for calculation of ABC scope 2 CO_2 emissions

S. No.	Description	Electricity Purchased (in kWh) (I)	CO_2 emissions Factor (in g CO_2/ kWh) (II)	Indirect CO_2 Emissions (in kg) (= I x II)

01	Electricity used in ABC	601649000	0.806	484929094

Therefore, Y = 0.4849 MT CO_2

Total carbon dioxide emissions in ABC Industry

= X + Y

= 26.6 + 0.4849

= 27.08 MT CO_2

ABC produces approximately 27.08 MT of CO_2 emissions for a cement production of 33.05 MT. It means that 0.8195 ton of CO_2 is emitted per ton of cement production.

Limitations

The import and export of clinker and other raw materials have not been considered. Certain assumptions like mileage of vehicle have been done well under the acceptable guidelines which may differentially alter the accuracy of the result.

VI. RESULTS AND DISCUSSION

The carbon footprint for the company ABC as calculated from the framework is now scope-wise tallied with the officially generated Sustainability Report 2019 of ABC as in the table below.

Table 12: Comparing Scope-wise ABC CO_2 emissions

Customized framework vs official sustainability report (2019)

Scope – wise emissions (MT CO_2)	Using customized framework	As reported in Sustainability Report of ABC
SCOPE 1	26.6	16.6
SCOPE 2	0.484929	0.534401
SCOPE 3	-	0.675988
Total	27.08	17.83

The above results indicate that for the production of 33.05 MT of cement, the CO_2 emissions as calculates using the framework and that reported by the company vary. From the customized framework, it has been concluded that (27.08/ 33.05) = 0.819 t of CO_2 is emitted per ton of cement production. While, it has been reported that ABC emits (17.83/ 33.05) = 0.539 t of CO_2 per ton of cement production.

VII. CONCLUSION

The framework is factual and incorporates every aspect of GHG emissions during the whole cement manufacturing process and may therefore be used for calculating CO_2 emissions of any Indian cement – producing company. During the CF analysis of ABC Company, it was found that the emissions reported were much lower then what should have been the case if proper methodology for CF analysis had been followed. Image enhancement, tax evasion and maintaining brand value might have been the motive behind the cause.

This work will also act as a guide to those who want to learn and apply this particular framework in calculating CF of Indian cement plants in future and plan the strategy to reduce the CO_2 emission.

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Figures

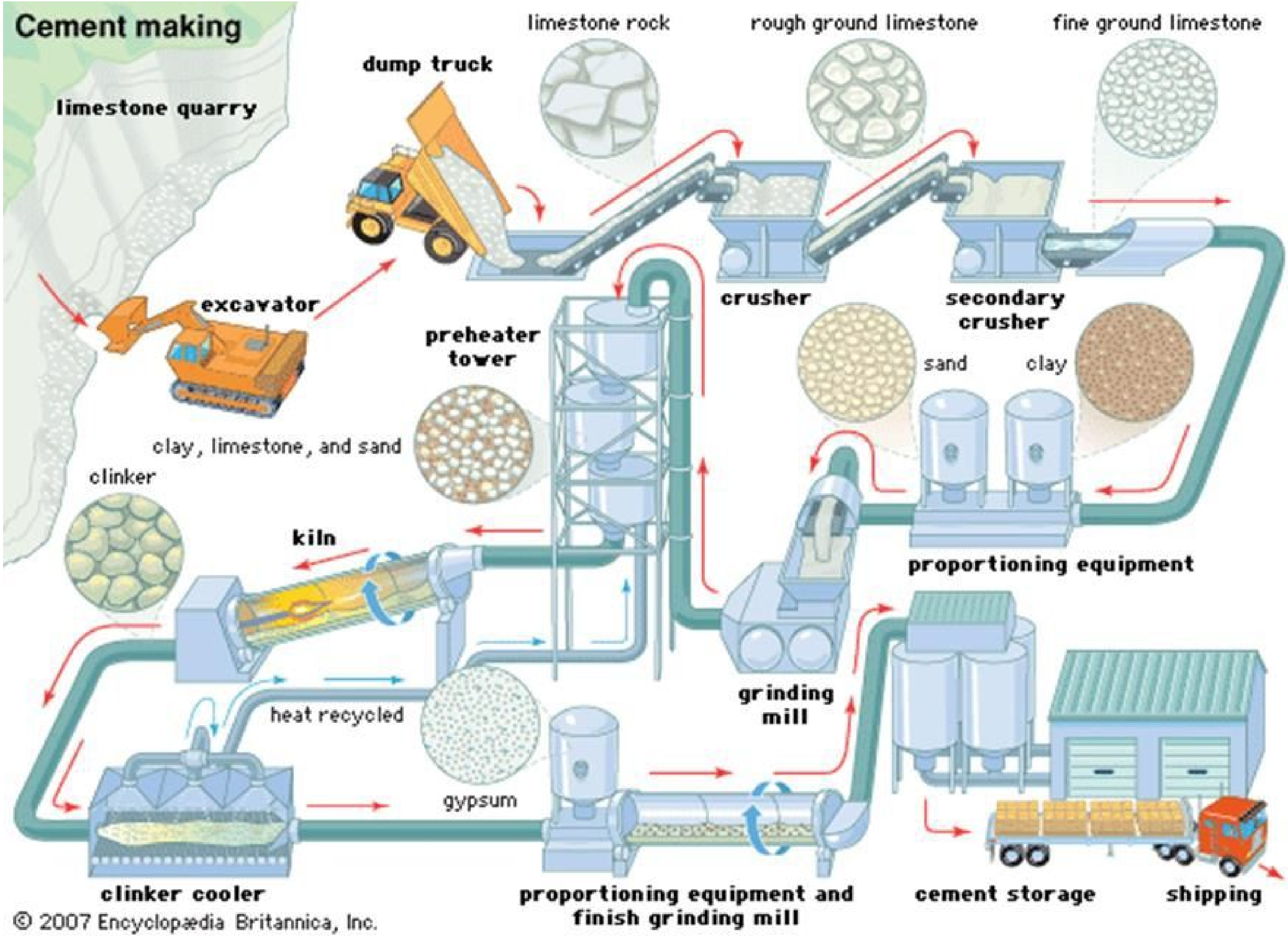

Figure 1

Cement manufacturing processes in a cement plant (Encyclopedia Britannica, Inc., 2007)

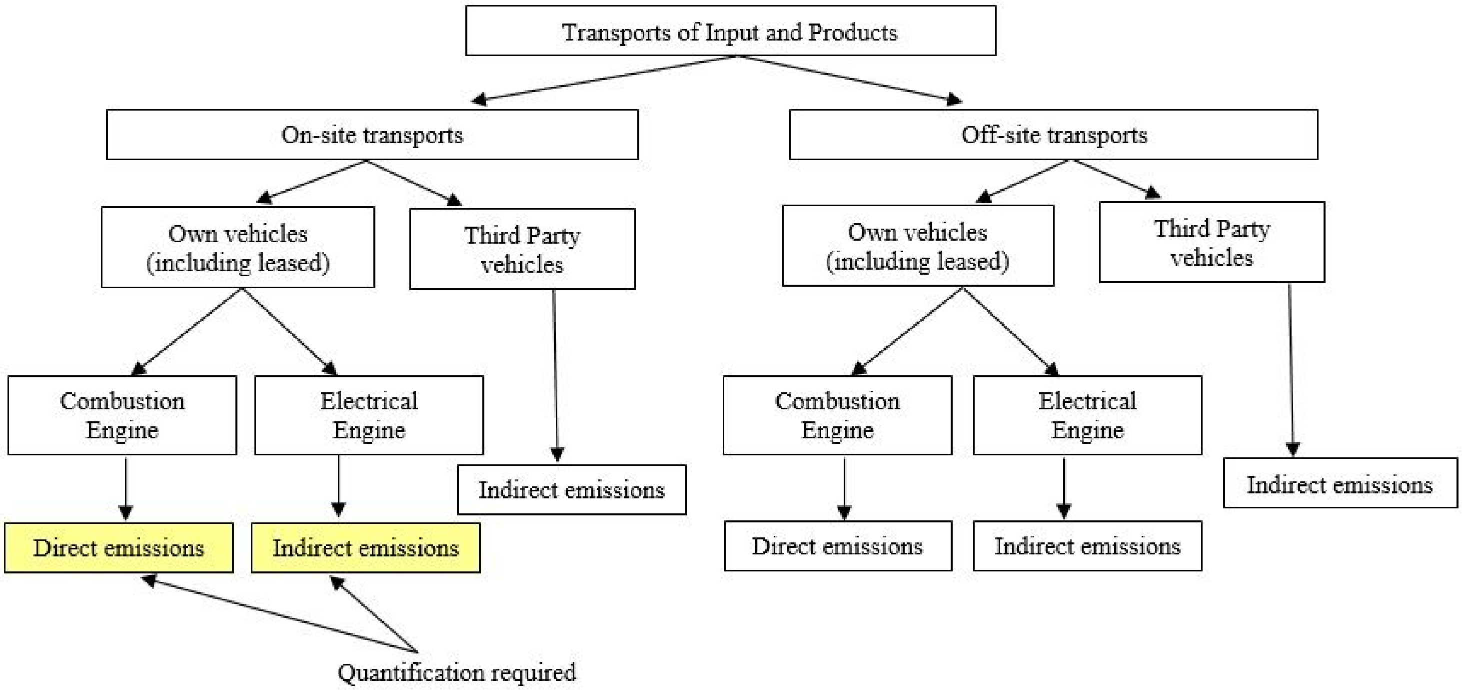

Figure 2

Breakdown of transports by type, and coverage (Indian Cement tool)