Carbon footprint of a multi-storied residential building during the construction process

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Abstract

Construction Industry indicates development of the country and it helps in the economic growth which adds productivity and quality of life of citizens. During the manufacturing and the construction processes, there is use and combustion of fossil fuels which results total 39% of total carbon footprint. So, studying carbon footprint for construction companies becomes very important. Many different studies are carried out with giving number of alternatives to reduce the amount of carbon footprint. However, this research is focused mainly on multi-storeyed residential building in renowned city in India, shows the carbon emissions produced by a construction activity right from the material production to the actual execution process. Different Greenhouse gases contributing carbon footprint were also studied & incorporated. Various activities accounting to emissions were listed and their carbon footprint value (in the form of Carbon Dioxide equivalent) was calculated by bottom-up method. The manufacturing of various construction materials and usage of electricity during execution phases of a building causes very bad impact on the environment. The greatest contributors of the carbon footprint are onsite electricity use and building materials manufacturing. Therefore, use of green concrete, renewable energy, prefabricated construction materials and low emission construction equipment & vehicles can help in reducing the values of Carbon Footprint by the construction industry.

Keywords

Carbon Footprint, Building Construction, Greenhouse gas, Sustainable construction

1 Introduction

The construction industry is a major contributor of greenhouse gases that increase global warming. 39% of the energy used worldwide is due to the construction industry and a quarter of the total amount of CO₂ emissions worldwide [1]. Production of materials such as metal, cement, bricks & lime results
in 80% of total extraction. During the production of these building materials, the use of very different energy levels and consumption of goods are also very high. The total energy and carbon emissions in 1989-90 of these four components are 742.5 Peta joules and 80.5 million tons of CO₂ emissions. Other developmental approaches conducted research in which they discussed the increase in demand for building materials in the construction sector due to the increase in housing demand by 2.4% per annum. The housing gap was 30.8 million homes before 2011 AD [2]. In the production of building materials, the extraction of raw materials, processing is possible, and the transport of building materials to the required sites, all these lead to more carbon emissions in the environment. Therefore, by studying carbon footprint, the environmental impacts of architecture can be minimized. The objectives to overcome this are-

1. To understand the different types of Greenhouse gases that contributes to Carbon footprint and discover the potential of Global Warming (GWP).
2. To add the various functions to the existing site that offers Carbon Footprint and estimate the total value.
3. To study the ways to calculate Carbon Footprint and calculate Carbon Footprint value manually.
4. To suggest alternative ways to reduce carbon footprint prices at construction sites.

2 Literature Review

2.1 Carbon Footprint- It is the amount of greenhouse gases (GHGs) produced by an individual, event, organization, service or product. It is produced in terms of equivalent CO₂. The combustion of fossil fuels, the earth's crust, and the diversity of its activities lead to greenhouse gases such as carbon dioxide and methane. Carbon Footprint is used to measure the environmental impact of many sectors such as Transport, Energy, Manufacturing and Construction. As a result of these activities, climate change such as a major acidification earthquake and a warm sea occurs. Since the beginning of the Industrial Revolution in the 1820's, climate change has been happening. People rely heavily on fossil fuels, energy use and deforestation, as the amount of greenhouse gases increases day by day. Reducing traces of greenhouse gases has been difficult to achieve [3].

2.2 Greenhouse Gases- GHGs increase global warming as infrared radiation absorption increases. It absorbs and emits radiant energy within hot flashes, as a result of which heat dissipates. Typical greenhouse gases are water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and ozone (O₃). Every gas has a variety of features, quantities and effects, with all its benefits being limited. For example, the direct effect of methane radiation is 84 times greater than that of carbon dioxide. Conversely, in combination with its direct effect of radiation, methane contributes to the formation of ozone [4].

High heat gases released by the construction sector-

2.2.1 Carbon Dioxide (CO₂) - Carbon dioxide is naturally occurring. It has a lot to do with health and is colourless and odourless. Emissions from carbon are increasing due to the increase in carbon dioxide emissions and deforestation. Also, the construction of a building and its equipment increases the emission of carbon dioxide. During the power outage, utilities, manufacturing, transport, construction, repair and disposal, CO₂ emissions occur [5].
2.2.2 Methane (CH₄) - Methane is a hydrocarbon and is the main source of natural gas. Methane is extracted from a variety of sources, both human and natural. Anthropogenic (human) sources of pollution are landfills, oil and natural gas systems, agricultural activities, coal mining, permanent and mobile suspension, water treatment and industrial processes. Considering about 20 percent of the world’s emissions, methane is the second largest GHG after carbon dioxide. Methane is more than 25 times as high as carbon dioxide [6].

2.2.3 Nitrous oxide (N₂O) - Nitrous oxide gas is a different form of nitric oxide (NO) or nitrogen dioxide (NO₂). Nitric oxide and nitrogen dioxide are not greenhouse gases, although they are essential for the process of producing ozone. There are several sources of nitrous oxide including natural and anthropogenic (human) sources. N₂O is produced due to car burns [7].

2.2.4 Hydrofluorocarbon (HFC) - HFCs are used in air conditioning, separation and fire extinguishing systems. The global heat capacity of HFCs is very high. Because of its increasing effects, it acts as ozone depletion agents. Economic growth encourages the need for new equipment, nowadays in the refrigeration / AC sector [8].

2.2.5 Perfluorocarbons (PFC) - Perfluorocarbons of greenhouse gases are very powerful. They have been introduced as an alternative to ozone depletion. PFCs can be used instead of chlorofluorocarbons (CFCs) in the production of semiconductors. Basically, they are used as solvents in the electronics industry. They are also used as refrigerators in the refrigerator system. PFCs are also used in the production of Aluminium.

2.2.6 Sulphur hexafluoride (SF₆) - Sulphur Hexafluoride appears as a colourless, odourless, non-toxic gas. About five times the thickness of the air. The global warming power of SF₆ is 23,500 times greater than that of Carbon Dioxide. SF₆ is an excellent electrical insulator. [9]

Table 1. Shows the various GHG’s with its chemical formula & GWP which helps to understand.

| Gases               | Chemical Formula | GWP   |
|---------------------|------------------|-------|
| Carbon Dioxide      | CO₂              | 1     |
| Methane             | CH₂              | 25    |
| Nitrous Oxide       | N₂O              | 298   |
| HFCs                | -                | 124-14800 |
| Sulphur Hexafluoride| SF₆              | 22800 |
| PFCs                | -                | 7390-12200 |

Greenhouse gases are categorized into two, viz. Direct and Indirect Releases. Direct emissions from sources are called direct release. During the construction process, the power consumption of equipment such as the excavator, bulldozer and piling machine, is less than the direct output. At the same time, on-site transport, electricity consumption, mixing such as chemical use, metal welding, waterproofing and painting, thermal heating and other on-site staff activities are considered direct emissions. Indirect emissions resulting from large operations are referred to as indirect discharge. It includes the production of building materials and their movement, the transportation of construction equipment on site and the activities of external workers [11].
3 Methodology

The above research was carried out at construction site located at Pune City, Maharashtra, India. The site was consisting of residential multi dwelling units with 99424 sq. ft. area.

3.1 Data Collection

Broadly material production, transportation, construction equipment’s and electricity used on the site are the main components that increase the carbon footprint value. So, the quantity of different materials used is listed in table 2.

| Material       | Quantity | Unit   |
|----------------|----------|--------|
| AAC Blocks     | 66224    | Blocks |
| Tiles          | 1035     | Sq. m. |
| Concrete       | 2783     | Cu. m. |
| Plaster        | 113      | Cu. m. |
| Water Proofing | 24940    | Sq. ft.|

Mostly all vehicles used on the site run on diesel. From removal and exhaustion to completion, use a variety of vehicles such as bulldozers, tractors, cranes, trucks, borehole excavators, concrete mixers, etc., which consume a lot of diesels. Fuel is one of the most widely used resources in any construction project. The quantity of fuel required for the earthwork activity at selected site is shown in table 3.

| Construction Process   | Quantity (cu. m) | Diesel consumed per km | Total Diesel Consumed (liter) |
|------------------------|------------------|------------------------|------------------------------|
| Excavation and earth removal | 5184             | 0.27                   | 1399.68                      |
| In situ earthwork      | 5184             | 0.03                   | 155.52                       |
| Earth filling, rolling and smoothing | 4172             | 0.25                   | 1043                         |
| Total                  |                  |                        | 2598.2                       |

Other uses of diesel while transporting these different materials from various locations to the site. The type of vehicle depends on the items to be transported. So, during travel, heavy vehicles are used to emit large amounts of GHG into the atmosphere. Therefore, in calculating all this pollution, first calculate the distance between the site and the city and then determine the amount of diesel or fuel used. Also, the movement of auxiliary engineers, contractors and operators leads to more diesel consumption. The diesel consumption on the site considered in case study is given in table 4.

Electricity is used by various construction equipment such as air compressors, hand tools, chain saws, electric welders, power planer, pumps, conveyors, router and test equipment etc. Construction sites often provide temporary accommodation for working workers and for energy-intensive activities. At the construction site, one unit cost is Rs. 9.75/kWh. Debts for various months were collected in the office. The total amount was Rs. 24,28,000. In all, no. of units used will be 2,49,025 kWh.
GHG’s such as CH₄, CO₂ and N₂O are released from the septic tank system. The total CO₂e for GHG emission per capita is a septic tank equivalent to 0.1 tonne CO₂e/capita year [8].

Table 4. Diesel quantity required at selected site.

| Construction Material | Transported from | Transported to | Distance (km) | Diesel consumed /km | Total diesel consumed (litre) |
|-----------------------|------------------|----------------|---------------|---------------------|-----------------------------|
| Tiles                 | Rajasthan        | 1249.4         | 0.286         | 357.3               |
| AAC Block             | Shirur           | 62.2           | 0.286         | 17.8                |
| Steel                 | Jalna            | 287.9          | 0.286         | 82.3                |
| Granite               | Rajasthan        | 1249.4         | 0.286         | 357.3               |
| Solar Panels          | Chakan Site      | 27.9           | 0.286         | 7.9                 |
| Paints                | Shirwal Site     | 63.4           | 0.286         | 18.1                |
| Concrete              | Jalna            | 287.9          | 0.286         | 82.3                |
| Bricks                | Hadapsar         | 13.2           | 0.286         | 3.7                 |
| Gypsum                | Deccan           | 21             | 0.286         | 6                   |
| **Total**             |                  |                |               | **933.1**           |

3.2 Methods of carbon footprints calculation

Carbon footprint is calculated from the bottom to the top approach. In this way the carbon emissions of each work are calculated separately and put together. So, in this case there will be no error in the calculation. Therefore, the results obtained by this method are accurate.

Step 1) Carbon account is provided by, Carbon account = AD * EF

Where, AD = Activity Data, EF = Release Feature

Step 2) CO₂e = AD * EF * GWP = carbon account * GWP

Where, GWP = Global Warming Power

Step 3) The Last Carbon Emissions are provided by,

\[(\text{CO}_2\text{e}) = \sum (\text{AD} \times \text{EF} \times \text{GWP})\]

4 Result & Discussion

The carbon emission at site located at Pune is given in table 5. The table elucidated the quantity of material required with its emission factor and generation of carbon emission.

Finally, GHG emissions caused by material production are very high and on the other hand more than 70% of emissions are due to concrete, steel, electricity and block production. Different materials use different type of energy source. Therefore, the options for our site will determine the amount and type of GHG emissions. It is best to use environmentally friendly building materials that emit low carbon
emissions. Many things need a second consideration, making it cleaner and more renewable. During the manufacturing and construction process, there is the use and heating of mineral oil which results in 39% of the total carbon emissions by the Construction Industry. Reducing the pollution of the post construction phase is difficult. Therefore, analysing the extraction before construction begins will help to reduce pollution. Analysis can be done by reading the construction and height drawings. With it we can determine the amount of material used, the amount of fuel used by vehicles and equipment and the electricity & water used on site. Finally, due to incorrect sources and quality of data collected, there were some limitations in this study and carbon footprint values were calculated.

Table 5. Carbon emission.

| Description   | Quantity | Unit   | Emission Factor | Per  | Carbon Emission (kgCO₂e) |
|---------------|----------|--------|-----------------|------|--------------------------|
| AAC Block     | 95231.4  | sq.ft. | 2.13            | sq.ft. | 202842.88                |
| Concrete      | 2783.08  | cu.m.  | 351             | cu.m. | 976861.08                |
| Steel         | 493687   | Kg     | 1.9             | Kg    | 938005.30                |
| Tiles         | 14,1126  | kg/sq. m | 16.8        | kg/sq. m | 237.09                |
| Granite       | 2.92     | Kg     | 0.879           | 1000 kg | 2.56                     |
| Wood          | 528      | Piece  | 18.45           | Piece | 9741.6                   |
| Gypsum        | 20,813   | kg/sq. m | 140.7       | 1000 kg | 2928.38                |
| Bricks        | 565      | Sq. m  | 427.98          | 1000 bricks | 241808.70            |
| Solar Panels  | 24       | Set    | 459.91          | set   | 11037.84                 |
| Elevator      | 11       | floors | 0.52            | floor | 5.72                     |
| Septic Tank   | 1        | capita/yr | 100          | capita/yr | 100.00                 |
| Electricity   | 2988307.68 | kWh/yr | 0.85            | kWh/yr | 2540061.52              |
| Diesel        | 3531.2   | Ltr.   | 2.653           | Ltr.  | 9368.27                  |

Total 4933000.97

5 Conclusion

After calculating the total amount of emissions, alternatives were obtained to reduce emissions during the construction and construction work. Rules for the use of low-carbon materials and equipment must be made. Raw concrete can be used in place of Portland cement for concrete. By products of industrial processes and materials can be used in cement. For ex. Portland cement can be replaced by fly ash. An average of 927 kg of CO₂e occurs every 1000 kg of Portland cement produced and since fly ash is a waste product, it does not require energy to produce. In the collection of fly ash at power stations it causes a discharge of 0.006 CO₂e per ton of fly ash. Also, GGBFS can be used. Gray furnace slag not only improves quality but also concrete strength and its production is CO₂ free. GGBS production emits 35 kg of CO₂/t, which is 22% less than Carbon Footprint of Cement.

Stable mud bricks (SMB) are a good alternative for clay bricks. SMB production does not need to be burned, it can be produced on site and used solid industrial waste such as stone, quarry dust, fly ash, etc. CO₂e in stable brick production is 228.03 kgCO₂e/m² and that of cement blocks is 396.8 kgCO₂e/m². Pre-made items can be used to make the work green. It will reduce waste as one will get the whole piece that will prevent having more resources. Trucks, tractors, JCBs, etc. are used for the
construction of jobs such as mining, transportation, etc. Therefore, by using a low carbon emissions vehicle, the carbon footprint can be reduced. High-powered construction equipment can be replaced with non-exhaust equipment. There are many products available in the market but no emerging consumers.

6 References

[1] Wang, C. & Tan. X., 2012 Estimating Carbon Footprint in the Construction Process of a Green Educational Building, *Proceedings of 2012 Int. Conf. on Construction and Real Estate Management Kansas City USA*, 1, pp 175-179.

[2] ‘Case Study for construction in India’ by development alternatives in structural transformation process towards sustainable development in India and Switzerland – published by INFRAS publication, Zurich.

[3] A bulletin on ‘What is Carbon Footprint?’ Archived from the original on May 2009. Retrieved on July 2009.

[4] ‘IPCC AR4 SYR Appendix Glossary’ Archived from the original on Nov. 2018. Retrieved Dec. 2008.

[5] Designing buildings wiki - ‘Carbon Dioxide in Construction’, reedited May 2021.

[6] Land Trust Alliance = ‘Carbon Dioxide, Methane, Nitrous Oxide, and the Greenhouse Effect’ – Conservation in a changing climate.

[7] Thompson M. 2006 *Greenhouse Gases: Nitrous Oxide (N2O)*

[8] ‘Reducing Hydrofluorocarbon (HFC) Use and Emissions in the Federal Sector through SNAP (Significant New Alternatives Policy) by United States Environmental Protection Agency.

[9] McGrath M 2019 *Electrical Industry’s dirty secret boosts warming*.

[10] IPCC 2007- Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change

[11] Hong J., Shen G., Feng Y., Lau W., Chao M 2015, Greenhouse Gas Emissions during the Construction Phase of a Building: Case Study in China’, *Journal of Cleaner Production*, 103.

[12] Leverenz H., Tchobanoglous G. 2011 Evaluation of Greenhouse gas emissions from Septic tank systems.