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Evaluating Carbon Footprint in the Construction Industry: Challenges and Mitigation Strategies

Jyoti Deupa* and Birendra Kumar Bohara
School of Engineering, Far Western University, Nepal
*Corresponding author email: jyotideupa44@gmail.com

Abstract

The construction industry plays a major role in global greenhouse gas emissions, contributing significantly to the world's overall carbon footprint. It accounts for approximately 39-40% of total annual emissions, with about 27-28% stemming from operational emissions and 11-13% from embodied carbon (United Nations Environment Programme, 2019). These emissions have a serious impact on climate change and environmental degradation. Despite this, there is still a lack of effective strategies to fully eliminate carbon emissions in the sector. This study focuses on identifying the primary sources of carbon emissions in construction, examining their impact and exploring the challenges in implementing reduction measures. It adopts a qualitative research approach, utilizing document analysis to gather data through an extensive literature review. Findings indicate that emissions from the construction industry continue to rise. The main contributors of CO2 emissions include the extraction and processing of raw materials, manufacturing of construction products, transportation to construction sites, emissions generated during operation and demolition at the end of a building's life cycle. Although both governmental and non- governmental organizations are actively working on policies to lower emission levels, the goal remains challenging. The World Green Building Council (WGBC) continues its ambitious mission to achieve a carbon-free construction sector by 2030. Strategies such as reducing material waste, using sustainable construction materials, adhering to green building standards and utilizing renewable energy sources offer promising solutions. However, among several challenges, top five challenges are high initial cost, shortage of material and skilled manpower, technology, lack of awareness and interest among stakeholders and government policies.

Keywords: Carbon footprint, sustainable construction, greenhouse gas emission, climate and environment

Introduction

The term carbon footprint refers to the total volume of carbon dioxide (CO_2) and other greenhouse gases (GHGs) emitted as a result of the actions or activities of an individual or organization (Geografie, 2019). Global warming and effects of Greenhouse gases (GHGs) are increasing day by day. Gases such as CO_2 are increasing in tremendous way from the consumption of resources and production of goods in the industry. The CO_2 emissions are increasing mainly from land use change and excessive use of fossil fuels due to the rapid population growth and rapid growth in per capita GDP (Geografie, 2019). Among all of the sources, construction industry is considered as the single largest global consumer of the non-renewable energy resources (Sizirici et al., 2021). Globally, in developed and developing countries, building's construction, operation, maintenance, repair and replacement contribute to 33% of the greenhouse gas emissions and 40% of the global energy consumption which stem from the equipment use, manufacturing of building materials and transportation (Sizirici et al., 2021). As per data based on Global Building Emissions (GLOBE) database building sectors are responsible for 37% of 2022 global carbon emissions (Ma et al., 2024). Also after construction of structure its operation, maintenance, repair of the structure and finally disposal of materials at the end of the lifecycle of structure are responsible for CO_2 emission (European Rental Association, 2019). Annual carbon dioxide emissions grew by about 80% in between 1970 and 2004, mainly due to extensive fossil fuel usage and land use which is still in increasing rate (Kumanayake & Luo, 2018).

According to Paris agreement signed by around 70 countries, the aim is to accelerate actions to eliminate the buildings and construction sector's emissions by 2050 (World Green Building Council, 2019). A research based on 44 countries found that China and India are top two countries with higher carbon emission in construction industries whereas the United Kingdom has the least carbon emission (Crawford, 2022).

The main objective of this study is to explore the challenges in implementing carbon reduction measures in construction industry and review existing and potential strategies to promote sustainable and eco-friendly construction practices.

Research Methodology

This paper is based in an extensive and systematic literature review aimed at gathering, analyzing and synthesizing existing knowledge relevant to the topic. A quantitative narrative review approach was adopted to identify key findings and research gaps within the selected domain. A combination of keywords relevant to the topic were used to refine the search strategy. The review focused primarily on peer-reviewed journal articles, conference papers, institutional reports published between year 2010 to 2025. Reference management tool Mendeley is used to organize the selected studies and remove duplicates. Finally, key data were extracted from the chosen literature to identify research findings and knowledge gaps.

Results and Discussion

Overview of Carbon Footprints of Construction Industry

According to ISO/TS 14067:2013 Technical committee carbon footprint is a measure a product contributes to the climate change, where all the greenhouse gas emissions during the product life cycle are considered (ISO 14092, 2013). According to the 4th assessment report of the Inter-governmental Panel on climate change (IPCC), GHG emissions from buildings contributed 8.6 billion metric tons (t) CO_2 equivalent (e) in 2004 and by 2030 with this high growth rate, it is expected to increase by 26% reaching 15.6 billion t CO_2 (Díaz et al., 2012). However, there is lack of systematic and accurate methods for carbon emission calculations and most of the studies are based on Life Cycle Assessment approach which focuses on indirect carbon emission (Labaran et al., 2021).

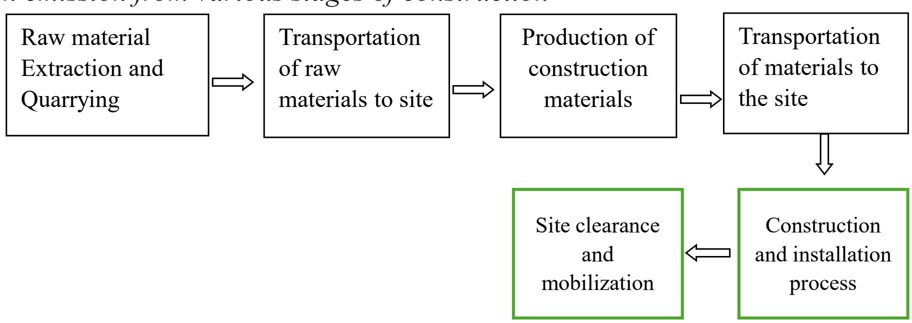
Construction industry involves consumption of materials which come from various sources either natural or artificially manufactured. Some of construction material which produced through manufacture process is cement, steel, bricks and so on while natural materials obtained from nature such as sand, wood and water (Marzuki et al., 2015). Based on implementation methods materials can be divided into two; on site and off site, although, both the methods need energy which is fossil fuel (Marzuki et al., 2015). The extraction and quarrying process demands certain amount of energy in several steps of material production (Wulandari & Sholihin, 2020). Building's carbon emission includes materials used during the construction of the projects, as well as the construction process, the service period of the structure and emission from the demolition of the structure after the completion of lifespan of the structure (Marzuki et al., 2015). Nowadays, several international standards exist for determining and certificating the carbon footprint in any organization as well as in any processes, such as ISO 14064-1 and GHG Protocol (ISO 14092, 2013).

Key Sources of Carbon Emissions in Construction

The construction involves various phases starting with material production, material transportation, and construction or installation period and these all phases act as the source of the carbon emission (Sizirici et al., 2021). The carbon emitted from these sources can be categorized into two categories as embodied carbon and operational carbon(UKGBC, 2021). Embodied carbon refers to the carbon emitted from extraction and manufacturing of all kinds of construction materials, transportation of those materials to the site, construction process, repair, maintenance and demolition after service life (Lützkendorf & Balouktsi, 2022) (UKGBC, 2021). While operational carbon is associated to the use of building services such as heating, cooling, ventilation and lighting system (UKGBC, 2021) (Anna Dyson, Naomi Keena, Mae-ling Lokko, Barbara K. Reck, 2023).

Figure 1

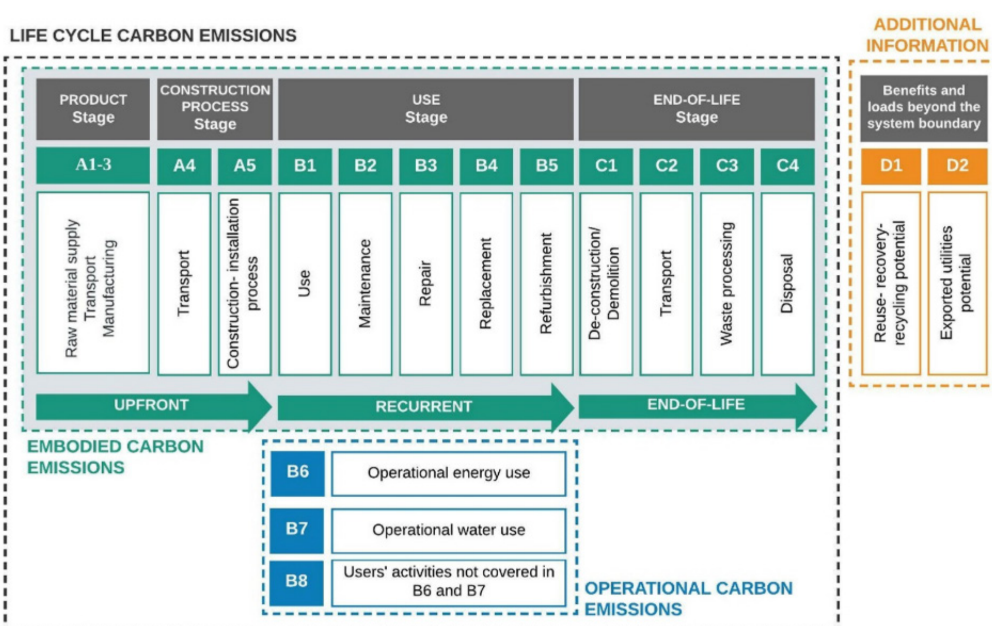
Carbon emission from various stages of construction



Note. Adopted from Weigert et al. (2022)

Figure 2

Carbon emission from different stages of construction



Note. Adopted from Lützkendorf & Balouktsi (2022)

On a study based on life cycle assessment in the UK, it was found that carbon emission from material extraction, manufacturing and production is 50.8-53.4%; from construction activities is 18.6-23.2%; from transportation of materials, plant and manpower is 8.2 – 10.3% and from other activities such as removal of waste, operation of building services and demolition is 16.1-19.8% (Giesekam et al., 2014).

Extraction and Quarrying of Raw Materials

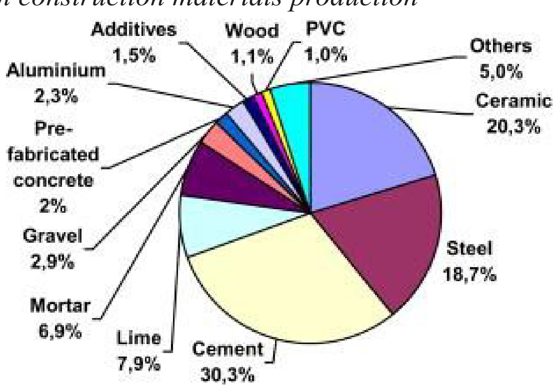
The major source of carbon emission in construction industry is extraction and quarrying of materials. Natural materials like stone, sand, fine aggregate. The process of extraction and quarrying need large to small scale equipment and machineries. Among building materials aggregate production only goes through following stages:- blasting, excavation, hauling and crushing (Bascetin et al., 2017). The transportation of raw building materials from the mining site to the material processing plant is also responsible for carbon emissions (Cheng et al., 2023).

Production of Construction Materials

The buildings and construction industry was responsible for 36% of final energy use and 39% of energy and process related carbon dioxide (CO_2) emissions in 2018, 11% of which was from manufacture of building materials and products such as steel, cement and glass (United Nations Environment Programme, 2019). The International Energy Agency (IEA) traces energy uses and direct emissions from production processes of high- volume materials such as iron and steel, cement, chemicals and petrochemicals, aluminum, pulp and paper (Hertwich, 2021). Steel and concrete are top two construction materials producing high carbon emission which is approximately 2/3 of overall carbon emission (Zainordin & Zahra, 2021). Primarily, three main construction components cement, ceramic and steel together contributes 44% of industrial carbon emissions in the UK (Giesekam et al., 2014).

Figure 3

Carbon emission from construction materials production



Note. Adopted from Bribian, et al. (2011) as cited in Marzuki et al. (2015)

The pie- chart above shows the percentage of carbon emission in production of different types of construction materials.

Transportation of Materials to Site

Transportation of building materials to the construction sites to initiate the construction process is responsible for generation of embodied carbon. Transportation of materials during an ongoing construction project releases about 6-8% of carbon. Plant machineries like excavators, cranes, back hoes and lorries have highest carbon emissions due to the use of fuels and lubricants (Zainordin & Zahra, 2021). In a research done in 40 construction project in Sweden, it was found that transportation of machines and materials to sites contribute to 10% of carbon emission (Sezer & Fredriksson, 2021). Taking three phases of construction i.e. building material transportation phase, building material production phase and construction phase, a study in China showed that building material transportation phase produces 42.51%, material production phase produces 41.78% and construction phase produces 15.71% of carbon emission (Chongxi & Zhang, 2024). From this, it is clear that carbon emission during transportation of materials to site play significant impact on GHGs and global warming.

Construction or Installation Process

Construction process involves clearing sites, excavation, installation or construction, finishing works, clearing wastage and removal of temporary structures. Each of these steps involves carbon emission. The case study in 61 construction sites in Denmark concluded that, on site transportation and construction process emits 0.28kgCO2/m2 and 1.00 kgCO2/m2 gross floor area respectively over 50 years which is about 13.47% of the Danish whole-life carbon (Kanafani et al., 2023).

Operational Stage Carbon Emission

Operational stage carbon emission is the carbon emitted from consumption of energy to operate the building services (UKGBC, 2021). Operational carbon is associated to the use of building services such as heating, cooling, ventilation and lighting system.

Demolition, Recycle and Reuse of the Materials (UKGBC, 2021) (Anna Dyson, Naomi Keena, Mae-ling Lokko, Barbara K. Reck, 2023)

After the completion of service life, process of demolition takes place followed by recycle, reuse or disposal of the waste. Demolition of building involves heavy duty vehicles such as excavators, graders, crushers and dumpers which run on diesel emitting CO2 while in operation (Weigert et al., 2022).

Effects of Carbon Emissions and Mitigation Measures

Reduction of carbon emission from any construction project specially buildings starts with design phase, as efficient energy utilization techniques and renewable energy consumption system with use of low carbon emission building materials significantly lower the total amount of carbon footprint (Krejza et al., 2019). For this, materials with high carbon emissions should be identified and should be replaced by low embodied carbon materials. Studies so far show that cement, steel and ceramic are top three contributors in material carbon emission (Lim et al., 2017).

Myint and Shafique in their comparison study found that use of low carbon steel, significant reduction in use in bricks and use of timber can lower the carbon emission by 39%(Myint & Shafique, 2024). Since, steel and cement are known to be the primary source of construction industry hence, reducing the use of these carbon intensive materials by low carbon intensive materials or techniques can significantly lower the carbon emission (Giesekam et al., 2014). Alternatives such as blended cement (cement with high volume of complementary cementing materials such as coal fly ash, silica fumes granulated slag and reactive rice-husk ash), compacted fly ash blocks (a high density compacted block made by mixture of lime, fly ash and stone crusher dust), Stabilized mud blocks for masonry (formed by compacting mixture of soil, sand, cement or lime and water and curing for 28 days) and rammed earth walls can be used instead of high carbon generating materials (Venkatarama Reddy, 2009). Clean construction i.e. minimization of on- site construction waste and fuel switching to renewable power sources can greatly help to achieve carbon neutrality (Ma et al., 2024). Use of Building Information Modelling supports accurate estimation and material optimization minimizing waste and saving the cost (Toochukwu, 2025). Green belt area can be increased to reduce the effect of carbon emission. Applying all these measures, carbon emission from construction industry can be reduced by 50% of the existing trend of carbon emission (Calvin Mwalwanda, 2012).

UN environment program prepared a report in 2022 which mentioned that to hit the target of decarbonizing construction industry we must work on improving building energy performance, decrease building materials' carbon footprint, multiply policy commitments and increase investment in energy efficiency. Using green building guidelines showed decrease in operational stage carbon emission which can be used while construction stage of the building (Zhou et al., 2021). Government policies and regulations regarding construction and Green Building guidelines, awareness and knowledge spread among stakeholders and people can also act as effective ways to lead construction industry to zero carbon emission (Abdullah et al., 2024).

Major Five Challenges in Implementing Mitigation Measures

1. Cost: Financial barrier is biggest challenge in implementing mitigation measure to reduce carbon emission. It is because client and contractor both want their

maximum benefit from their project regardless of any other factors (Abdullah et al., 2024). Applying low carbon material approach for construction projects increases cost of the construction compared to traditional approach (Amarasinghe et al., 2024). A comparative study done in traditional construction approach and use of low carbon material approach revealed that there is 6.7% increase in the cost of construction for using low carbon materials in building construction (Myint & Shafique, 2024).

2. Material and Manpower: Lack of availability of low carbon materials and skilled and trained manpower who can understand and convince the stakeholders to apply techniques switching from conventional construction method is seem to be a another biggest challenge (Abdullah et al., 2024). Limited resources to invest in implementing emission mitigation strategies and no skilled manpower to optimize those resources is ranked as second among barriers in carbon emission reduction practice in Malaysian construction practices (Mustaffa et al., 2022).
3. Technology: Lack of technology used in production of low carbon materials and their utilization is big challenge especially in developing countries (Mustaffa et al., 2022). As well as using hybrid vehicles or electric transportation , minimizing transport distance, monitoring and tracking energy consumption in each stage of construction and optimizing machines could be the other ways to tackle with the higher emissions (Abdullah et al., 2024).
4. Awareness among stakeholders: Generally, the key stakeholders involved such as client, investor and contractors have less understanding about the low embodied carbon building techniques and they end up trusting traditional method of construction (Amarasinghe et al., 2024). In organization level as well there is found less interest among companies towards the impact of emissions and the implications on the environment. Also, organizations are more focused in short term profit instead of adopting sustainable practices (Mustaffa et al., 2022).
5. Government regulations and policies: Lack of strict government policies and strategies is given lowest rank among the other challenges but the strict actions of government towards sustainable and zero carbon emission construction can lead organizations to follow up sustainable practices for construction (Abdullah et al., 2024).

Conclusion

As development of infrastructures is increasing worldwide resulting in emitting carbon footprint during whole construction and operation period. Several studies discussed impact of carbon emission to environment and whole eco-system and suggested ways to decrease the carbon emission focusing on replacement of construction materials and adapting to sustainable construction practices. Substitution of cement, ceramic and steel along with replacement with renewable source of energy for building operation are considered as most effective ways to mitigate the problem of carbon emission. Despite the discovery of the solutions to minimize carbon emissions and challenges to implement the solutions there is continuous increase in carbon emissions. Five major challenges in implementing mitigation measures were found in the study.

To effectively minimize carbon emissions in the construction and built environment sectors, it is essential to begin by identifying and prioritizing the primary sources of emissions and the major challenges associated with them. Accurate quantity estimation methods must be employed throughout all phases of a project to reduce material wastage and promote efficiency. Additionally, the development of appropriate tools and techniques for calculating carbon emissions during the operational stage of a building is crucial for long-term sustainability. Finally, policy frameworks and regulatory standards should be tailored and implemented in proportion to each country's carbon emission levels, ensuring that measures are both equitable and effective in addressing global climate goals.

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