J Sustain Const Mater Technol, Vol. 6, Issue. 3, pp. 101–115, September 2021

Journal of Sustainable Construction Materials and Technologies
Web page info: https://jscmt.yildiz.edu.tr
DOI: 10.29187/jscmt.2021.66

Review Article

The carbon footprint of construction industry: A review of direct and indirect emission

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ARTICLE INFO

Article history
Received: 01 May 2021
Accepted: 13 July 2021

Key words:
Carbon footprint, construction industry, direct emission, greenhouse gas, indirect emission, lifecycle assessment, review

ABSTRACT

The construction industry is considered to be among the major sectors that contribute significantly toward the emission of GHGs in our environment, which have a major effect on the climate change, and is approximately responsible for about 19 percent of the overall GHG emission globally, rendering it a pollution hotspot requiring urgent mitigation measures. Unfortunately, there are few studies on this subject to help construction companies meet their low-carbon targets. As a result, this paper reviewed the contributions of researchers across the globe towards carbon dioxide and other GHGs emissions from the industry. After a systematic review of some of these studies, it was found that the majority of researchers focused primarily on a specific feature of the construction industry, a case study of a particular country/city or region, using the Life Cycle Assessment approach. And, even those who have studied similar aspects such as cement or steel, have all used different methodologies, units, and techniques of reporting. As such, a comparison between the findings of the literature is unrealistic. Despite this, the scope of the emission from the construction industry is remarkably clear, and the carbon findings can be found throughout the literature.

Cite this article as: Labaran YH, Mathurb VS, Farouq MM. The carbon footprint of construction industry: A review of direct and indirect emission. J Sustain Const Mater Technol 2021;6:3:101–115.

1. INTRODUCTION

The sudden growth in the greenhouse gas emissions within our environment was initiated from the industrial age till around the end of the eighteenth century [1]. Human activities are the primary contributors to all these emissions by the consumption of fossil fuels and desertification, which increases the amount of greenhouse gasses in the atmosphere at an immense rate [1, 2]. The increase in CO_2 has become the agreed level above which the consequences of climate change will become dangerous. The impact of these actions on humankind will be pervasive and lead to disruptive weather disasters, agricultural production instability, and public health challenges [3]. CO_2 is one of the dominant compound elements of the greenhouse gases and the principal causal factor of global warming [4]. It accounts for almost 82% of overall global warming, with the remainder coming from active greenhouse gases, meth-

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ane, and nitrous oxide [5]. The United States Energy Information and Administration estimated that by 2035, global carbon dioxide emissions would grow to around 7 percent higher than that in 2007 [6]. This suggests a potential rise in overall greenhouse gas emissions in many countries [6]. In his study, Wei Huang et al. [7] found a percentage rise in the annual average growth rate of the carbon footprint from buildings in the urban areas of Xiamen between 2005 and 2009. The carbon footprint growth between 2005 and 2007 was low, but it started to leap in 2008 [6]. In general, he found that there was an increase in the CO_2 emissions from the onsite construction activities, production of construction materials, building waste disposal, building use, and material transportation [7]. In addition to that, a November 2018 study from the United Nations World Meteorological Organization found that average global CO_2 concentration in 2017 exceeded 405.5 ppm, higher than that of 2015 and 2016, in which the concentration was 400.1 ppm and 403.3 ppm respectively [5]. The increment of these emissions in our atmosphere has caused the average global temperature to rise over the past 100 years by more than one degree Celsius [1, 8]. However, if left uncontrolled, the average temperatures of the earth may increase in the next coming 100 years by about 4.5 degrees Celsius or even more [1, 8]. Related research studies on economic, social, as well as other aspects were undertaken by various governments, organizations, and scholars, attempting to discover a low-carbon opportunity for sustainable development [9].

Global warming and several other environmental issues have stirred up strong international community concerns [9]. A series of international treaties have been signed, such as the "Bali Roadmap (2007), the UN Framework Convention on Climate Change (1992), the Copenhagen Agreement (2009), and the Kyoto Protocol (1997)", demonstrating the Government's commitment to respond to the global warming [9, 10]. Countries have made promises on pollution cuts and a plan of action according to the consensus has been finalized. Thus, the revolutionary ideas of the low-carbon life, low-carbon economy, carbon tax, low-carbon environment, and carbon trading, etc. have become the world's primary development strategy [9]. The 2015 to 2050 period can be considered as an era of transition phase toward net-zero emissions for both buildings as well as the physical environment reflecting the agreement reached by the numerous countries attending the Paris "COP 21" [11] in 2015 [4]. The conference saw a big milestone with various stakeholders from around the world agreeing that environmental change is a shared problem for humanity. They decided that steps and measures need to be implemented to keep the average temperature of the earth well below 2 degrees Celsius with attempts to restrict the warming around 1.5 degrees Celsius [1, 11]. Because of such agreements, Malaysia attempted to minimize about 40% per capita of its carbon and other GHG emissions by 2020 [12]. Also, the United Kingdom has set out big plans for the zero-carbon rating of all new household and commercial structures by 2016 and 2020 [13]. These are among the world's most advanced sustainable goals for the built environment [13]. The construction sector is making a rapid transition toward net-zero carbon and energy buildings infrastructure. Today, the NZE Buildings are more often affordable and widely available across many countries [14]. Unfortunately, there are fewer studies on this dimension to help companies meet their low-carbon targets. As such this paper focuses on examining the numerous contributions of researchers across the globe towards carbon emission from the construction industry. To this end, a systematic review of the carbon footprint studies of the construction industry were undertaken, highlighting the key results and gaps for future research.

2. METHODOLOGY

A total of 105 research papers were collected originally for the study focusing on the carbon footprint of the construction sector in general, of which only 61 were chosen for the study offering a more detailed overview of the construction industry from multiple perspectives [15]. Two steps were used to improve the quality and reliability of the literature review sources [13]. The first step was carried out using structured keywords in high-quality scientific repositories and journals, including Scopus, ScienceDirect, ResearchGate, Google Scholar, and the rest from other reputable journals such as Hindawi, Academic Journal of Science, American Journal of Engineering Research, Journal of Mechanical and Civil Engineering, Journal of Environment and Earth Science, etc. Most of these articles have been published or cited over the last ten years, to ensure reliability. Various keywords were used to obtain the materials, some of which include, carbon, carbon footprint, green building, sustainable construction, zero carbon, cleaner production, carbon assessment, sustainable building materials, rating system, etc. The search found that there were a small number of papers dealing specifically with the carbon footprint of the construction industry and very few major reviews in the field. The second step consisted of industry and university studies, governments and international agencies reports, internet and media publications, etc. most of which are frequently alluded to by numerous stakeholders in the construction industry when contemplating concepts related to carbon emission aspects. This study includes databases approved by well-established sources such as the IPCC report, the World Bank records, and UN studies and reports, etc. Majority of the review studies have some limitations [13], but, in this study, a strong emphasis was placed on discussing the general research results and content analysis by various authors on the carbon footprint of the construction sector, rather than targeting specific articles, writer, or a specific aspect of the industry. The process used in establishing this study is demonstrated in the Figure 1 [13].

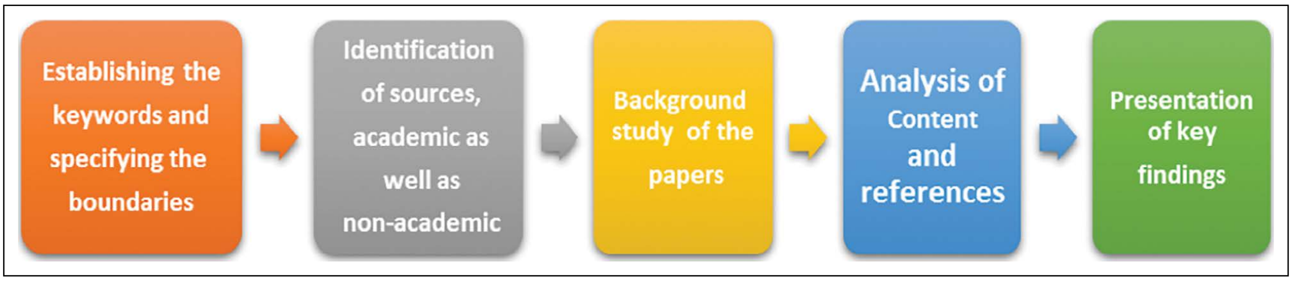

Figure 1. Literature review workflow (adopted from Zaid Alwan et al. 2015).

3. DEFINITION OF KEY TERMS

3.1 GHG

Greenhouse gas is a general name for a group of gases containing CH_4, CO_2, N_2O, SF_6, HFC, and PFC that usually trap heat from the sunlight in our atmosphere, and they are the essential causative factor for the persistent rise in the average temperature of the earth [16].

3.2 GWP

The potential of retaining sunlight heat by a particular GHG based on its absorption capacity in the atmosphere is called the global warming potential of that respective gas, which is determined over a given period. The primary objective of using GWPs is to transform a particular GHGs into CO_2e, which is the common method of global emission reporting [16].

3.3 CO_2e

CO_2 equivalent is a statistical scale that is used for the evaluation and measurement of different GHGs emissions on the basis of their GWP. The CO_2e of a particular gas can be obtained by the multiplication of its weight by its related global warming potential as described in equation 1. Below [16];

"$kgCO_2e$=(weight of the gas in kg)×(GWP of the gas).......... (1)"

3.4 CF

The carbon footprint is the cumulative quantity of GHG emissions generated by a person, firm, company, activities, or items, measured in CO_2e, and expressed in tons of carbon dioxide emissions per year [17].

3.5 LCA Approach

The Life cycle assessment aims to identify the environmental impact that any services or goods may have from its beginning (cradle) to its end (grave). The definition of cradle to grave concept implies that; the consequences from the extraction to final disposal of a product is properly considered over its entire life cycle, these, however, include all the activities in between such as production, transportation, packaging, processing, and other associated services [18–20].

4. CARBON FOOTPRINT OF CONSTRUCTION INDUSTRY

The construction industry is considered to be among the major sectors that contribute significantly toward the emission of GHGs in our environment through the mechanism of energy usage, various GHGs emissions associated with the energy production, and generation of waste, etc. And due to its significant contribution to higher GHGs emissions, Mahmure et al. [21] regarded the construction industry as one of the major drivers toward the persistent rise in temperature and global warming in general. Zaid Alwan et al. [13] added that construction has particularly impacted the environment through the production of waste, CO_2 emissions, change of land use, loss of biodiversity, and climate changes. However, these problems appeared more in developing countries, for example, 24% of the CO_2 generated in Malaysia comes from the construction sector [22], in India 130,477 Gg which is equivalent to 53.4% of national CO_2 [23], in Nigeria, the emission from the construction and manufacturing industries increased from 2557 to 23714 Gg of CO_2 equivalent between 2000 and 2015 reflecting approximately 827% increase as observed which is much above normal [24].

The "U.S. energy information and administration" reported that the CO_2 emission globally will increase, by the year 2035, to about 42.7% higher than that of 2007. Thus, showing an increment of greenhouse gases in many countries [6]. However, almost 40% of the total amount of these emissions are from the construction sector [10, 18, 19, 25], in which materials consume 10–20% out of the 40% from their production to demolition, including all the related emissions from their construction, transportation, and even renovation activities, etc. [19]. The "Sustainable Building and Construction Initiative (SCBI) of the United Nations Environment Program (UNEP)" reported that 30-40% of global energy demand is from the construction industry, which is expected to grow at an average of 1.5% to 3.4% rate in the next coming 20 years. In practical terms, the buildings contribute annually to the atmospheric emission with about 8.1 Gt of carbon dioxide [4, 26]. Tathagat D. et al. 2015 have recognized that buildings accounted for 33 percent or 7.85 Gt of all the global CO_2 emissions related to energy, and the emissions are forecasted to rise by 2030 to about 11 Gt or even much higher value of 15.6 Gt [10]. It can therefore be identified as a major contributing sector to carbon emissions that requires urgent mitigation for a sustainable future. Several studies on carbon emissions from the construction of various types of structures have been carried out by different researchers globally, some of which are presented in Table 1.

4.1 Direct and Indirect Emission

For a given construction project there are two major components of CO_2 emissions, Direct emission (operational CO_2) and Indirect emission (embodied CO_2) [49]. The operational (Direct) CO_2 emissions are usually generated from the consumption of energy at the site and during other various construction activities, while indirect carbon emissions are generated through the extraction of construction materials, production, transportation, demolition, and other non-building activities [9, 7]. The construction industry's carbon footprint is a concept that takes into accounts all the environmental impacts of CO_2 and other GHGs generated during various construction activities [25]. This includes all the emission impacts related to the materials used during the construction of the projects, as well as other emissions impacts related to the construction process itself, the service period of the structure, and even the various emissions associated with its demolition [27]. Shihui Cheng et al. 2020 [29] reported that direct energy use consists of only 9.8% of the construction process of his study with 358.8 kt CO_2, while the emissions from the material production constitute 90.2 percent, reaching 3310.2 kt. In his study, "Jingke Hong, et al. 2014" [27] indicated that the manufacturing of construction materials and the energy usage at the site were the major sources of CO_2 for both embodied and operational GHG emission, with 97 percent of the total emissions coming from indirect sources. He further identified numerous sources of GHG emissions from his research on GHG emissions during the construction process of a building in China, in which he categorized the emissions as direct and indirect, the summary of the categories is presented Table 2 [27].

Environmental impacts in construction projects arise from the extraction of raw material to its final disposal, this, however, includes all the related activities in between including manufacturing, installation, distribution, maintenance, and demolition, which are based on the LCA process [50]. Using a similar scenario, Wei Huang et al. 2017 [7] used five components to measure the CF of buildings; construction materials production, transportation, the construction process, direct energy usage, demolition, and waste disposal [7]. Apart from that, other studies follow a similar pattern while measuring, estimating, reporting, or developing tools related to the CF of the construction sector. Some of which include a study by J. Giesekam, et al. 2016 [52], Jennifer Monahan 2013 [3], Institute of Civil Engineers (ICE) [51], Fei fei Fu et al. 2014 [28] among others.

4.1.1 Extraction and Quarrying

It involves the extraction of precious minerals and other natural resources from the earth, typically from the ore, lode, vein, shale, reef, or deposit [53]. Mining is necessary to acquire any material that cannot be produced agriculturally or artificially in a laboratory or factory. Materials extracted by the mining process include gemstones, iron, potash, oil shale, coal rock, chalk, calcareous stone, clay, salt, and gravel, etc. [53], that are primarily used in the construction industry.

The mining sector produces an annual Greenhouse gas emission of between 1.9 and 5.1 gigatons of Carbon dioxide equivalents (CO_2e) [54]. Mineral resources are presently being drawn from the earth more frequently and often faster than in the last 4 to 5 decades [55]. The world consumes over 92b tons of metals, biomass materials, minerals, and fossil fuel every year, and this estimated value is increasing by about 3.2 percentage rate yearly [55]. Nonetheless, many countries are not having adequate mining industries, which means that they have to import fully or semi-processed products and base metal concentrates to meet their ultimate demand, however, as they import these materials and products, they also import and contribute to their related environmental impacts [56]. The mining activities including the extraction and processing of the minerals generate nearly 20 percent of the total air pollution health implications, and 26 percent of the total global carbon emissions [55]. Even with all those massive amounts of carbon emissions, the sector has just begun to set carbon mitigation targets [54]. Theoretically, extraction can be decarbonized completely (except for fugitive methane) [54].

4.1.2 Materials Production

As new buildings are becoming more energy-efficient, material-related emissions account for a higher percentage of their overall impact on environmental changes. Developers, builders, architects, and planners are becoming more mindful of the building material's impacts on climate change and are gradually incorporating considerations of environmental issues while selecting techniques and procurement of various construction materials [2]. Feifei Fu et al. (2014) [28], reported that; 97 percent of the overall carbon emission of his study is from embodied construction materials, with the remaining 3 percent coming from cradle to site transportation. He further found that the main contributors to these emissions were blocks, steel, and concrete used during the construction, which together contributed to more than 60 percent of the total emission [28]. A similar report by Jingke Hong et al. (2014) found the top 10 major construction materials that accounted for about 86.6% of all carbon emissions of his study, with steel and concrete as the best two [27].

The construction sector is society's largest energy user which consumes about 40% of all the generated energy through the production of building materials such as steel and cement [10, 57]. In particular, materials production needs more energy, generates more waste, and pollutes natural resources [58]. The fast expansion and rapid development of the manufacturing industry would inevitably lead to an increase in the overall CO_2 emissions globally [59].

Table 1. Reviewed studies on various type of civil engineering projects

Reference	Country	Referenced from	Type of structure	Main material	Floor area	Method	Quantity of CO_2
Jingke Hong et al. (2014) [27]	China		Residential complex	Reinforced concrete structure	11508 m^2	LCA Process	8707004 kg CO_2e
Feifei Fu et al. (2014) [28]	UK		Single story training center	Masonry wall Timber frame wall	180 m^2	LCA process	432 kg CO_2/m^2 363 kg CO_2/m^2
Shihui Cheng et al. (2020) [29]	China		High speed railway line	Concrete and steel	120 km	Hybrid I-O LCA	3669.0 Kt CO_2
Shashwath Sreedhar et al. (2016) [16]	India		Highway pavement construction	Bituminous concrete Portland cement concrete		Computer program took lit	3.09×107 KgCO_2e 3.89×107 KgCO_2e
Rossi et al. (2012) [30]	Belgian	Jingke Hong et al. (2014) [27]	Residential building	Masonry Steel	192 m^2	Process LCA	189 kg CO_2e/m^2 164 kg CO_2e/m^2
Surahman and Kubota (2013) [31]	Indonesia	I. C. Ezema et al. (2016) [4]	Simple residential house Medium residential house Luxury residential house		57 m^2 127 m^2 300 m^2	Hybrid LCA analysis	575 kg CO_2/m^2 721 kg CO_2/m^2 942 kg CO_2/m^2
Konig and Cristofaro (2012) [32]	Germany	Jingke Hong et al. (2014) [27]	Residential building		970–7292 m^2	Process LCA	430 kg CO_2e/m^2 (average value)
Abanda et al. (2014) [33]	Cameroon	I. C. Ezema et al. (2016) [4]	Houses	Mud brick Cement blocks		ICE database	228 kg CO_2/m^2 397 kg CO_2/m^2
Brunklaus et al. (2010) [34]	Sweden	Jingke Hong et al. (2014) [27]	Residential building	Concrete, wood		Process LCA	400 kg CO_2e/m^2
I. C. Ezema et al. (2016) [4]	Nigeria		Residential block	Reinforced concrete frame	720 m^2	Survey and LCA methods	2395 kg/m^2
Blengini and Carlo (2010) [35]	Italy	Jingke Hong et al. (2014) [27]	Residential building	Reinforced steel concrete	250 m^2	LCA	"770 kg CO_2e/m^2"
"Nassen et al. (2007)" [36]		Jennifer Monahan (2013) [3]	Detached dwelling Multi-occupancy dwelling			LCA Cradle to occupation	264 kg CO_2/m^2 360 kg CO_2/m^2
Ortiz et al. (2010) [37]		Jingke Hong et al. (2014) [27]	Residential building	Bricks based Not mentioned	125 m^2 108 m^2	Process LCA	246 kg CO_2e/m^2 257 kg CO_2e/m^2
Hacker et al. (2008) [38]	UK	Jennifer Monahan (2013) [3]	Light weight timber frame Heavy weight concrete	Timber Concrete		LCA Cradle to occupation	492 kg CO_2/m^2 569 kg CO_2/m^2
Williams et al. (2012) [39]	UK	Jingke Hong et al. (2014) [27]	Construction of office complex	Reinforced steel concrete		LCA	467 kg CO_2e/m^2
Jennifer Monahan (2013) [3]	UK		Timber framed house with larch cladding	Larch and timber	83 m^2	LCA	405 kg CO_2/m^2

Table 1 (cont.). Reviewed studies on various type of civil engineering projects

Reference	Country	Referenced from	Type of structure	Main material	Floor area	Method	Quantity of CO_2
			Timber framed house with brick cladding	Brick and timber			535 kg CO_2/m^2
			Conventional house, made with masonry cavity wall	Masonry			612 kg CO_2/m^2
Wallhagen et al. (2011) [40]	Sweden	Jingke Hong et al. (2014) [27]	Office building	Reinforced concrete	3537 m^2	Process LCA	160 kg CO_2e/m^2
Atmaca and Atmaca (2015) [41]	Turkey	I. C. Ezema et al. (2016) [4]	High-rise 13 floor apartment Low-rise 3 floor residency	Reinforced concrete		LCA	5222 kg CO_2/m^2 6485 kg CO_2/m^2
Wu et al. (2012) [42]	China	Jingke Hong et al. (2014) [27]	Office building	Reinforced concrete	36,500 m^2	Process LCA	803 kg CO_2e/m^2
Li, et al. (2013) [43]	China	I. C. Ezema et al. (2016) [4]	Residential building		1460 m^2	LCA	1238 kg CO_2/m^2
"Van Ooteghem and Xu (2012)" [44]	"Canada"	Jingke Hong et al. (2014) [27]	Commercial building	Hot-rolled steel Structure made with a heavy "Pre-engineered steel" "Steel-PREDOM" "Timber-PREDOM"	586 m^2	LCA	549 kg CO_2e/m^2 517 kg CO_2e/m^2 355 kg CO_2e/m^2 522 kg CO_2e/m^2 451 kg CO_2e/m^2
"Kua and Wong (2012)" [45]	Singapore	Jingke Hong et al. (2014) [27]	Commercial building	Reinforced steel concrete	52,094 m^2	LCA	"121 kg CO_2e/m^2"
"Yan et al. (2010)" [46]	"Hong Kong"		Commercial building	Reinforced concrete	43,210 m^2	LCA	"525 kg CO_2e/m^2"
Alam and Ahmad (2013) [47]	Bangladesh	I. C. Ezema et al. (2016) [4]	Residential building	Stone Bricks	502 m^2	LCA	9941 kg/m^2 1274 kg/m^2
Filimonau et al. (2011) [48], (adjusted)	UK	Jingke Hong et al. (2014) [27]	Hotel		3300 m^2	Process LCA	761 kgCO_2e/m^2

Table 2. GHG sources

Direct emission	Indirect emission
1) Energy consumption of construction equipment such as;	1. Building materials productions and transportation
• Bulldozers	2. "Transportation of construction equipment"
• Excavator	3. "Offsite staff activities, including;"
• Piling machine etc.	• "Offsite electricity use"
2) "Onsite transportation"	• "Staff transportation"
3) "Construction electricity use"	• "Fugitive discharge from septic"
4) "Assembly and miscellaneous works" such as;	• "Water production and discharge"
• "Welding process"	
• "Chemical use"	
• "Waterproof paint"	
• "Reserve holes"	
• "Pipe binder etc."	
5) "Onsite worker activities" such as;	
• "Cooking oil consumption"	
• "Fugitive discharge from septic"	
• "Water production and discharge"	

Adopted from Jingke Hong et al. 2014 [27].

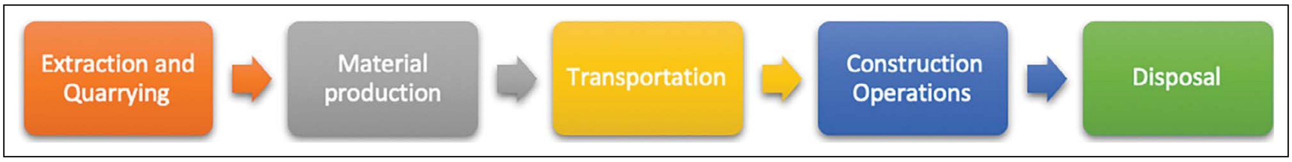

Figure 2. Process of carbon generation from construction industries [3, 7, 28, 51, 52].

Table 3. CO_2 emission coefficient and waste rate for the production of construction materials

Materials	Timber	Aluminium	Glass	Cement	Steel
CO_2 emission coefficient of the material	0.200	9.677	1.582	1.169	3.672
Rate of waste	5%	2.5%	5%	2.5%	5%

Source: [7, 62, 63].

Apart from that, the value-added of the manufacturing sector was found to be the most significant positive driver of the CO_2 emissions growth [60]. Jian Liu et al, 2019 [59] state that the carbon dioxide emissions from the manufacturing sector in china increased by around "220.77%" from 1995 to 2015 and contributed to about "58.27%" of the country's carbon dioxide emissions. Nigeria is reported as one of the highest emitters of CO_2 from the manufacturing and construction industries in Africa, with a total fuel combustion rate of about 12.2 percent in 2014 [61]. Another study by Wei Huang et al. (2017) revealed that the CO_2 emissions from the production of material for construction purposes are responsible for more than 45 percent of the overall footprint of the industry. while on the other hand, the emissions from the use of resources accounted for about 40 percent, and carbon emissions from the transportation of building materials were just about 1%.[7].

The carbon dioxide emissions from the production of materials including, iron, flat glass, aluminium, timber, steel, and cement are generated through the life cycle process of the production [7]. In which the manufacturing process of iron and steel produces the highest volume of the total carbon emissions from all these materials [56]. Chen W Q et al. [62], and Zhu Y et al. [63] conducted a research study on the cases of environmental emissions and LC energy use from the production of materials used in residential constructions, in which they found the CO_2 emission condition for the production of some of the major construction materials including timber, aluminium, glass, cement, and steel as described Table 3.

The embodied CO_2 of materials used in a particular building is determined by the amount and types of various materials used during the construction process. The choice of suitable construction materials therefore directly defines the type of the energy source as well as the quantity of CO_2 emission based on material type, material quality, and the emission factor of each of the materials [28]. Some of the reviewed studies related to the carbon footprints of various construction materials are tabulated Table 4.

In general, the production of construction materials contributes significantly to the overall CO_2 emissions of the industry, with 2/3 of the total emissions mainly coming from the production of concrete and steel. However, the emission from these two materials is connected to their manufacturing processes including cement production and steel processing, which are among the economic sectors that are heavily dependent upon fossil energy usage [27].

4.1.3 Transportation

Transportation is the movement of people and goods from a particular location to another. It includes the transportation of various construction personnel, machinery, and materials such as steel, reinforcement, fine and coarse aggregates from the original supply source to the project site [28]. Transportation and supply of various materials and equipment often affect our environment significantly by the mechanism of additional energy consumption while moving and conveying them from the production to the assembly points and finally to the project site [58]. Due to these environmental effects, this transportation activity has drawn considerable attention as it is among the primary contributors toward higher CO_2 emissions globally [66]. "The Intergovernmental Panel on Climate Change (IPCC)" reported that the transport industry generates about 13 percent of the overall global GHG emissions annually [IPCC Climate Change (2007)] [16]. In his study, Yi Yang, et al. (2019) reported that, the carbon footprint of some major megacities including New York, London, Tokyo, and others are mainly connected to building constructions, and transportation activities, with the manufacturing sector not having more than 10% proportions [67]. Also, according to the Asian Development Bank [68], transportation contributes to about 13% of the total GHGs globally and 23% of CO_2 emission related to energy usage [68], out of which 3/4 of all the transportation-related emissions is directly related to the road freight traffic [68]. Road freight in the UK accounts for about 22 percent of the transportation sector's emissions, or 6 percent of the country's total CO_2 emissions [66]. In the United States, freight transportation accounts for about 78 percent of the total emission from transportation activities, and the percentage of the overall transportation's GHG emissions rose from about 24.9 percent in 1900 to about 27.3 percent in 2005 [66]. Related figures were also reported in China, where the road freight activities generate about 30% of the total transportation sector's CO_2 emissions [66].

A study by Raymond J. Cole [69, 70] found that employee transportation to and from the construction site typically led to higher CO_2 emissions than either the on-site machinery used or the movement of materials and equipment to the job site [69, 70]. The research study finally revealed that, based on the assembly of the work, the movement of workers to and from the work site added between 5 to about 85 percent of the entire Greenhouse gas emission [69, 70]. In addition to these studies, other researchers have identified the emissions resulting from the transportation of different building materials with regard to either fuel consumption, loads, or distance, some of which include the following Table 5.

Transportation emissions are rising faster than in other energy-using industries and are forecasted to increase worldwide by 80% between 2007, and 2030 [66]. Many scientific consensuses exist on the need to drastically minimize our GHG emissions to prevent severe environmental changes such as global warming in the upcoming years [68].

4.1.4 Construction Operation

Throughout the stages of major construction projects such as foundation works, road construction, site preparation, and maintenance activities, etc., diesel-driven construction machinery contributes significantly towards air pollutions and GHGs in the environments [73]. Pollutants from equipment such as carbon monoxide (CO), PM 2.5, PM 10, and Nitrogen oxides endanger our environment and pose a potential risk to the health of the people and other living species [73]. Different construction activities and processes have different working requirements and conditions, which affect the equipment's working period under various engine status and load conditions [7]. For construction works such as hauling, digging, compaction, packing, lifting, and backfilling, etc. "off-road construction equipment" is usually deployed for the operation [73]. The off-road equipment's carbon emissions come from the fuel and energy usage during these activities [28]. Carbon dioxide is produced from the burning of fossil fuel through activities involving power generation, production of various materials such as concrete, and combustion of solid waste [20].

However, it is difficult to quantify and measure the actual emissions from the equipment as they fluctuate with many impacting factors [73]. Estimating the exact amount of emissions is a complex job due to the lack of monitoring data and measurement. The measurement of the emission nowadays can only be performed based on the time of operation, specified emission rates, deterioration of equipment, and load factors. The emission can also be calculated based on the amount of fuel consumed by the engines during a given time. Pollutants and CO_2 emissions from the gasoline-based construction vehicles are major risks to climate, industry, government, and the public in general [73] as they release a substantial volume of GHGs into the environment. Hence, the selection of suitable construction management techniques in the use of construction equipment, human activities, and transportation should be emphasized [27].

Table 4. Reviewed studies on the CO_2 emission of 18 construction materials

S/N	Material	Type of building	Reference	Country	CO_2 emission
1	Cement	Type of building	Jingke Hong et al. (2014) [27]		0.759 kg CO_2/kg
		Residential complex	Shashwath Sreedhar et al. (2016) [16]	India	0.8207 kg CO_2e/kg
		Highway construction	Hammond & jones (2008) [64]	UK	0.83 kg CO_2/kg
			Hammond & jones (2011) [45]		0.95 kg CO_2e/kg
			Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	1.165 kg CO_2e/kg
2	Steel	Highway tunnel	Jingke Hong et al. (2014) [27]		1.45 kg CO_2/m^3
		Residential complex	Shashwath Sreedhar et al. (2016) [16]	India	4.67 kg CO_2e/kg
		Highway construction	Jennifer Monahan (2013) [3]	UK	3.81 kg CO_2/kg
		Timber frame house	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.43 kg CO_2e/kg
		Highway tunnel	Purnell (2013) [43]		0.43 kg CO_2e/kg
3	Timber	Residential complex	Jingke Hong et al. (2014) [27]		583 kg CO_2/m^3
4	Glass	Residential complex	Jingke Hong et al. (2014) [27]		1..09 kg CO_2/kg
5	Aluminium	Residential complex	Jingke Hong et al. (2014) [27]		5.9 kg CO_2/kg
		Timber frame house	Jennifer Monahan (2013) [3]	UK	8.231 kg CO_2/kg
6	Crushed sand	Highway tunnel	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.005 kg CO_2e/kg
7	Concrete	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.1741 kg CO_2/kg
		Residential complex	Jingke Hong et al. (2014) [27]		261 kg CO_2/m^3
8	Bitumen	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	0.426 kg CO_2e/kg
9	Gypsum	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.30615 kg CO_2/kg
10	Brick	Timber frame house	Jennifer Monahan (2013) [3]	UK	0.519 kg CO_2/kg
11	Ceramics tile	Conventional building	Judit Nyári (2015) [19]		0.6125 kg CO_2e/kg
12	Copper sheet (roof)	Conventional building	Judit Nyári (2015) [19]		0.9732 kg CO_2e/kg
13	Wooden door	Conventional building	Judit Nyári (2015) [19]		18.450 kg CO_2e/piece
14	Wooden window	Conventional building	Judit Nyári (2015) [19]		42.175 kg CO_2e/piece
15	Fly ash	Highway tunnel	Mahmure Övül Arıoğlu Akan et al. (2017) [21]	Turkey	0.01 kg CO_2e/kg
			Purnell (2013) [43]		0.01 kg CO_2e/ton
16	Super plasticizers	Highway tunnel	Mahmure Övül Arıoğlu Akan et al (2017) [21]	Turkey	0.01 kg CO_2e/kg
17	Lime	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	2.81 kg CO_2e/kg
18	Aggregates	Highway construction	Shashwath Sreedhar et al. (2016) [16]	India	0.0028 kg CO_2e/kg

Table 5. CO_2 emission from transportation activities

Reference	Country	Materials	Load	CO_2 emission
Ozen & Tuydes (2013) [71]	Turkey			2.66 kg CO_2/ litre
DEFRA (referenced from Mahmure Övül Arıoğlu Akan et al. 2017) [21]	UK		24 ton	0.918 kg CO_2/km
Thomas et al. (2019) [72]			30 ton	33.81g CO_2/ton per km
Wei Huang et al. (2017) [7]	China	Cement		28.57/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey		24 ton/round	1.01 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Steel		9.71/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey		24 ton/round	0.95 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Sand		57.9/100 m^2
Mahmure Övül Arıoğlu Akan et al. 2017) [21]	Turkey	Natural sand	27 ton/round	0.95 kg CO_2/km
	Turkey	Crushed sand	27 ton/round	1.01 kg CO_2/km
Wei Huang et al. (2017) [7]	China	Gravel		120.48/100 m^2
Wei Huang et al. (2017) [7]	China	Timber		1.3/100 m^2

Most of the data are adopted from [7].

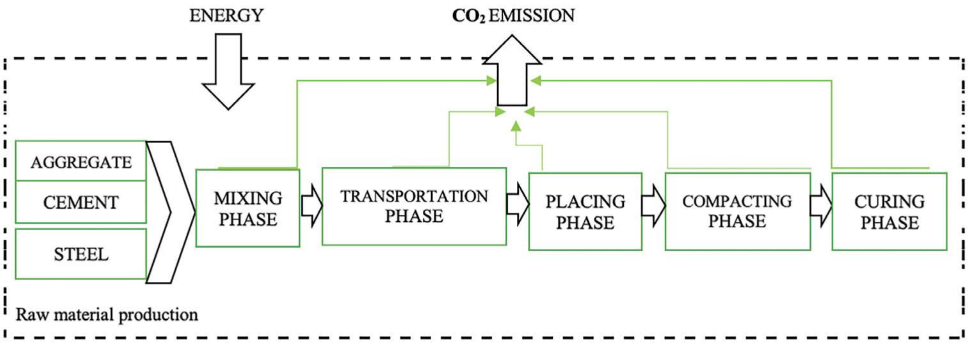

Figure 3. Emission from concrete production [74].

The Figure 3 describes some of the processes which emit carbon during the production of concrete at the site [74].

A large amount of CO_2 is released during these processes through the heavy construction equipment operations that add to the industry's overall carbon footprint from different activities, including mixing, transporting, placing, compacting, and curing [73]. As demonstrated in the above figure;

- The CO_2 emissions of the mixing phase are derived mainly from the consumption of energy by the mixing machines. Also, the mixing cylinder, sieving, control system, weighting components, and material transferring components are all electrically operated [74], which also contributes to the total CO_2 emissions through its generation.
- The emission of the transportation phase is attributed to the pollution emitted by vehicle engines, conveyor belts, and other transportation equipment [74].
- In the laying and placing process, the emission is derived from the consumption of energy by various equipment used for laying and fixing materials [74].
- The GHG emission of the compacting process comes from the rollers and vibrators' diesel/energy consumption [74].
- And lastly, the emission of the curing phase comes mainly from the consumption of fuel by the trucks and equipment used for curing the materials [74].

4.1.5 Demolition and Disposal

Building activities can generate a significant amount of waste materials that need to be disposed of, besides, it has to be deconstructed or demolished at the end of its useful life cycle, producing large quantities of waste [51]. The carbon emission from disposal activities is primarily derived from the initial embodied emissions of the recycled materials as well as the transfer of materials after the construction activities to other areas outside the project's site [28]. The construction industry uses 40 percent of the world's overall raw materials and it produces about "136Mt of waste" in the US alone per year [19]. In the United Kingdom, the industry generates approximately about 70 million tons of waste annually, out of which 13 million tons are disposed of [58]. Although there are alternatives for recycling and reusing materials for the amount of waste produced in the first place, there is still a significant amount of waste being disposed of in landfill [51]. Energy is consumed to demolish the construction, recycle certain materials and disposal of others by transporting debris and waste to landfill sites or incinerators [75]. Hence large quantities of CO_2 will be generated from activities that are carried out by heavy construction equipment which, in return, will make a significant contribution toward greenhouse gas emissions.

5. DISCUSSION

The discussed papers in this review are not an extensive list of all the research studies conducted in this field, but it is easy to see proof of so many challenges, for example, the limits of each case study are often different. Some studies use a lifecycle assessment in which they study the entire impact of the concerned project or structure. While others only consider the emission measurement during extraction, production, or transportation of a particular material in their study [1]. The literature review found that the quantification for the construction sector did not put much focus on capturing the sector's overall potential greenhouse emissions and reduction potential [15]. Nonetheless, many of the reviewed studies concentrated more on the indirect emissions and were mostly restricted owing to the inadequate comprehensive off-site and on-site process information due to limited system boundaries, especially the data related to various miscellaneous works and assembly as well as human activities associated with the construction. Apart from that other observation were made from the analysis of the literature as summarized below;

- The majority of the studies analysed the carbon footprint concerning a particular country, city, or region of developed countries and were mostly funded by the public authorities. While on the contrary, developing countries and Africa, in particular, has a very minor share of the studies [15]. Hence, there is a desperate exigency for a CF study of other numerous construction activities and the industry itself in developing countries where massive amount of CO_2 is generated every year, for example, 24% of CO_2 generated in Malaysia comes from the construction sector [22]. In India, the transportation sector generates around "161 MMT" of CO_2, making it 3rd in the world's annual CO_2 emissions, which is responsible for about 6 percent of the total emissions globally as reported in 2016 [53, 15]. Similarly, in Nigeria, the emission from the construction and manufacturing industries Increased from 2557 to 23714 Gg of CO_2 equivalent between 2000 and 2015 reflecting approximately 827% increase as observed which is much above normal [24].
- The literature review found that, more than 50 percent of the studies use the process-based LCA as their main methodological approach for quantifying the construction sector's CO_2 emission. Other approaches used include input-output analysis, Hybrid LCA, surveys, structural decomposition analysis, computer-programmed tools, and simulation [3, 1, 15]. And despite the fact that many of the research findings were based on the LCA techniques, most of these methodologies were often largely employed for buildings or regional CF analysis without focusing much on the consumption-based CF of various construction activities taking into account the unwavering importance of transportation and construction processes [15, 28]. However, even though some researchers have recognized the emission effect from the construction process, it should be noted that many other activities in the construction industries such as electrical fittings, waterproofing, thermal insulation, and painting, etc. that produce additional greenhouse gases were often omitted in such studies [27]. As such, there is a need for a thorough study on the greenhouse gas emission of a construction site using full system boundaries, including on-site assembly processes and human activities related to the construction, among many others.
- After analyzing each particular source of emissions and numerous studies in the literature, it can be seen that the activity with the greatest potential for GHG emission reduction were building material production. As such studies should be focused on addressing various sustainable construction material with a lower carbon footprint for use.
- Lastly, there are very few papers that discussed the estimation of the CO_2 emissions pertaining to infrastructural projects. And, apart from a paper by Jingke Hong, et al. 2014 [27], there is no other paper found in the reviewed studies presenting a systematic, open-access, and functional tool that would enable researchers across the globe to estimate the construction's CF comprehensively, and because of that, a comparison between these studies is not realistic owing to the wide variability in the reported figures and the different assumptions and presumption made by the authors [72]. This shows areas where steps can be taken to minimize the carbon emissions not just in the construction sector itself but also in many other interconnected sectors such as transportation, mining, manufacturing, among others [15].

6. CONCLUSION

Several researchers have studied the various contributions of the construction sector towards GHG emissions. However, from the systematic analysis of some of these studies, it has been found that the majority of researchers are primarily focused on a case study of a particular country, city, or region using life cycle assessment methods [3, 1]. In general, comparisons between the results of the reviewed papers are unreasonable as many of the findings were different, some of the authors examined only one particular aspect of the construction, some towns, some countries, etc. And even those who have studied similar aspect, such as cement or steel, have all used separate methodologies, different techniques of reporting, and even the units used were mostly different. Despite this, the scope of emission from the construction industry is remarkably clear, and the carbon findings can be found throughout the literature [3][9, 72]. Various ways to reduce the CF of the construction industry have been widely discussed, but most of the strategies are designs to mitigate the near future climate change impact without considering the impact in the longer future [18].

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The author declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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