

Investigation of Carbon Emission from Construction Waste in the Building Construction Process

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Abstract:

Significant efforts have been made to reduce carbon emissions across the design, building, and operation phases of construction. However, there is a lack of focus on measuring carbon emissions from the recycling of building waste at the end-of-life stage. The objective of this study is to conduct a quantitative analysis of carbon emissions from building waste in Erbil City. The Life Cycle Assessment (LCA) method is employed to quantify the energy consumption and environmental impact of construction materials. The Life Cycle Impact Assessment (LCIA) primarily aims to quantify environmental impacts, such as CO₂ emissions, by examining their effects on specific environmental factors. This study emphasized calculating the carbon emissions from energy and chemical processes in prefabricated materials and the corresponding carbon produced during the service stage, including logistics, electrical consumption, and energy use. An investigation is conducted on the carbon emissions associated with primary components of building waste like concrete, brick, steel, wood, mortar, etc. The calculated carbon emission for one ton of construction waste is 231.7 Kg, from using steel, cement, and blocks, which are considered high-carbon, energy-intensive materials. This research has the potential to measure carbon emissions and contribute to achieving carbon neutrality in Erbil City. The presented methodologies can be extended to other locations, particularly where data on building debris is limited.

Keywords:

Carbon emission; Construction waste; Embodied energy; Building materials; Life cycle assessment (LCA).

Highlights:

- The article indicates how to quantify different Construction materials Waste and managerial measures for assessing the carbon footprint of distinct building waste, including the total contribution of waste to the overall carbon emissions in the construction industry.
- It identifies and categorizes the primary sources and types of construction waste that contribute to carbon emissions.
- The article highlights more promising avenues for greenhouse gas emissions: reductions through improved planning, material utilization, and advanced construction technologies.

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1. INTRODUCTION

Nowadays, global warming, the phenomenon of increasing global surface temperatures, is one of the major concerns in environmental management and protection [1]. Although it has considerable intrinsic scientific uncertainties, anxiety about the adverse ecological and socio-economic effects has led to it being raised at the United Nations Framework Convention on Climate Change [2]. It is well known that, among the gases causing greenhouse effects, CO₂ emissions from the combustion of fossil fuels are the major contributing compound [3]. Therefore, most nations worldwide are attempting to reduce CO₂ emissions [1]. KRG, and especially Erbil city, is facing environmental problems, including air pollution. Air pollution sources arise from many factors, including carbon emissions from various construction materials. Between 2013 and 2018, 119 large industrial establishments were documented, primarily focused on producing materials for domestic construction projects. Their environmental statistics are closely linked to their operations [4]. In Erbil, therefore, it is essential to continue efforts to reduce CO₂ emissions and improve construction technology to make it environmentally sound and sustainable. To do so, one needs to consider the overall environmental burdens generated by construction during its entire life cycle. The purpose of this study is to classify and quantify the CO₂ emissions throughout the life cycle of several types of residential buildings in Erbil (i.e., from building material manufacturing, construction, and operation through demolition). The results of this study will serve as a basis for the eco-design of buildings [4]. This study examines the disparity and correlation between the carbon emissions of prefabricated buildings and the energy consumption of buildings. It provides a detailed explanation of the carbon emission coefficient for different energy sources and analyzes the characteristics and factors that influence this coefficient [5]. Cao et al. [6] in their study, they computed the carbon dioxide emission factor of fossil fuels in China. Utilizing the principles of life cycle assessment (LCA), A comprehensive analysis of the carbon emissions associated with buildings was conducted. The several factors influencing these emissions have been examined, the scope of accounting for carbon emissions has been defined, and the model has accurately measured carbon emissions throughout the entire life cycle of a building. The study did not target carbon emissions. Beginning in the industrial age and continuing until the late 18th century, greenhouse gas emissions in our atmosphere increased rapidly [1]. The primary causes of these emissions are human activity, including the burning of fossil fuels and desertification. As a result, the

amount of greenhouse gases in the atmosphere rises noticeably [1, 4]. There is a general agreement that the consequences of climate change would become seriously dangerous if carbon dioxide level CO₂s continue to grow. These actions will have far-reaching effects on humanity, including public health issues, unstable agricultural output, and extreme weather disasters [5]. One of the main contributors to greenhouse gases and the main cause of global warming is CO₂ [5]. It is responsible for around 82% of global warming, with active greenhouse gases, methane, and nitrous oxide accounting for the remaining amount [7]. Wei Huang et al. [7] discovered an increase in the annual average growth rate of the carbon footprint from buildings in metropolitan regions of Xiamen between 2005 and 2009. The carbon footprint increased modestly between 2005 and 2007, but surged significantly in 2008 [8]. Overall, he observed a rise in the carbon dioxide CO₂ emissions stemming from several sources, including onsite construction operations, manufacture of construction materials, disposal of building waste, building usage, and transportation of goods [7]. Furthermore, a study conducted by the United Nations World Meteorological Organization in November 2018 revealed that the average worldwide concentration of carbon dioxide CO₂ in 2017 was 405.5 parts per million (ppm), surpassing the levels recorded in 2015 and 2016, which were 400.1 ppm and 403.3 ppm, respectively [9]. Various governments, organizations, and scientists have conducted research on economic, social, and other factors to identify low-carbon opportunities for sustainable development [5]. To achieve this objective, a comprehensive analysis of the carbon footprint study conducted in the construction industry was conducted, focusing on the main findings and areas requiring further investigation. The construction sector has traditionally been recognized as a significant source of environmental harm, due to the substantial volume of waste generated by construction, demolition, rehabilitation, and related activities. Construction waste often includes materials generated by activities such as construction, demolition, remodeling, real estate development, infrastructure development, earthworks, and land-clearing operations [10, 11]. The composition includes, but is not limited to, wood, concrete, metal, brick, drywall, roofing materials, packaging materials, plastics, papers, cardboard, and other materials. Categorizing construction waste involves analyzing the composition and quantity of waste generated during construction. This process helps to improve our understanding of the origins and factors contributing to waste formation. Erbil relies heavily on fossil fuels for power generation. The

demand for electricity in Erbil has risen due to population expansion and rising electricity needs in residential and commercial settings. The emission variables associated with the combustion of various fuel types for electricity generation using different technologies play a crucial role in determining the pollution rate. Three distinct energy sources are utilized. Half of Iraq's energy is produced from petroleum gas, 28% from steam generators fueled by heavy oil, and 15% from diesel generators. The sole surviving supply consists of the hydroelectric power generators [12]. The capital city of Baghdad has the highest generating capacity, accounting for around 23.5%. The primary emissions from power generation units consist of Carbon dioxide CO₂, Carbon monoxide CO, Sulfur dioxide (SO_x), Nitrogen oxide (NO_x), particulate matter, and total organic compounds (TOCs) such as volatile organic compounds (VOCs) and semi-volatile organic compounds [13]. The emission rates of carbon dioxide CO₂ and carbon monoxide from combustion sources depend on the fuel's oxidation efficiency. C&D waste refers to solid waste generated by construction, demolition, and repair activities. It is sometimes referred to as construction garbage. Typically, it consists of both inactive materials (such as concrete and brick) and non-inactive elements (like wood and plastic) [14]. When construction waste is produced at the construction site, the initial step is to manually segregate the components that can be recovered before they are sent to landfills or recycling facilities [15]. Numerous studies were undertaken in different nations about the management of building and demolition of debris. However, demolition work accounts for the highest proportion of solid waste recycled [16]. Furthermore, the aforementioned research indicates that wood, concrete, tiles, bricks, and steel reinforcement constitute the majority of solid waste in Thailand [17]. The primary purpose of accurately calculating the quantity of construction and demolition (C&D) waste created or recovered in municipal solid waste (MSW) streams is to facilitate the implementation of comprehensive materials recovery programs. Diverting and recycling construction and demolition (C&D) waste from the solid waste stream can conserve natural resources, reduce greenhouse gas emissions, minimize landfill space requirements, and save money [18]. Given the significance of carbon-emission energy management research, numerous research teams have initiated investigations into carbon emission methods and development models, yielding commendable outcomes. The author in [19] examined the carbon emissions resulting from the manufacturing and transportation of accessories, as well as the fuel consumption of construction vehicles. This analysis enabled a

reasonable estimate of the associated carbon emissions and quantification of the corresponding environmental effects. The author accounted for the carbon emissions from recycled materials by subtracting them to avoid duplication. Additionally, the author accounts for carbon emissions associated with the installation of fiber-optic cables, diesel consumption by mobile machinery workshops, and electrical energy consumption. Life cycle evaluation method is quite effective. Due to its rigorous assessment logic and exceptional accuracy, it is widely used across diverse study domains to address several challenges [20]. The authors conducted a comprehensive analysis of LCA databases that contain data on building materials. They created criteria to assess the functionality and standards of these databases and used them to compare different databases.

2. METHODOLOGY AND DATA COLLECTION

The main criteria and methodology of our endeavor are to sort and identify the significant material contained in construction waste. This study needs to understand the life cycles of the relevant materials. The Life Cycle Assessment (LCA) method is commonly used to assess the energy consumption and environmental impacts of construction materials. The Life Cycle Impact Assessment (LCIA) focuses on quantifying all environmental outcomes, such as CO₂ emissions, by analyzing their effects on the selected environmental factors.

The study aims to:

- 1) Identify and aggregate the construction waste.
- 2) Contribute the material waste to the construction waste.
- 3) Measure the life cycle, the construction waste materials are (Iron, Steel, Aluminum, Copper, Concrete, Concrete block, Brick, Mortar, and wood)
- 4) We will insert three phases into the life cycle to quantify construction waste emissions.
- 5) The path is from mining the raw material, through manufacturing, to transportation, and then to the end of the material's life. [Table 1](#) presents the details of our intent phases with their sources.

3. LIFE CYCLE ASSESSMENT PHASES

3.1. Phase 1: Material Embodied Impact and Carbon Emission Calculation

As part of the material embodied impact, this study aims to quantify CO₂ emissions from the production and manufacturing sectors, which are relevant to each construction waste material. The primary resources are obtained from the chemical industry in the Kurdistan region and other Iraqi cities. CO₂ emission data taken from cement, ready-mix, bricks and steel plants in addition to other small factories. The approaches have been developed for the different sectors, as shown below.

Table 1 Life Cycle Assessment Phases.

Phases	Life cycle assessment phase	Sources
Phase 1 Material Embody Impact	Raw material mining/quarrying Manufacturing and Production and packing Intercanal Logistic and transportation	Cement Plant, Ready Mix Plant, Steel Factory, Wood Factory and Others
Phase 2 Processing and Logistic	Processing Logistic	Calculate later processing and manufacturing Applying survey from construction project
Phase 3 End of life	Calculating material contribution in construction waste Transportation Residual waste to land fill Recycling	Preparing a survey and questioner Average data from each journey applying survey from construction project applying survey from construction project

3.1.1. Cement Plant

Cement production is considered a very high-emission source among other manufacturing plants. Three cement plants (Mass, Delta and Bazyan cement plant in Suleimani city) are relied on to collect the CO₂ amount from chemical and energy processing. Decarbonization is a key focus in these plants to increase profitability by reducing fuel and electrical energy costs. The annual average measurement shows around 630 Kg of CO₂ emitted for producing one ton of Cement, this included energy consumption of calcining CaCO₃, electrical consumption and operating equipment for mining and transportation.

3.1.2. Electrical Power Generation

All construction material manufacturing is strictly linked to electrical consumption. The electrical source accounts for 85%-95% of the total energy used to produce construction materials (concrete, mortar, concrete blocks, etc.), compared with 30%-40% for steel, brick, and cement plants [21]. Table 2 presents the

CO₂ power released from each generator source across all Iraqi power plants relative to their annual power generation capacity. It is concluded that 231 Kg of CO₂ is emitted to produce 1 MWh.

Table 2 Percentage of Electrical Generation in Iraq VS CO₂ Emission.

Electric plants operational source	CO ₂ /MWh	Contribution
Heavy or crude oil plant	273.1	25%
Gas Plant	218.4	64%
Diesel plant	312.8	7%
Hydroelectric plant		4%

3.1.3. Other Construction Materials with Their Embodied Carbon Emission

Many carbon-emission data gathered from various industrial plants and factories, in this study, we are focusing on significant Domestic building materials. Specifying embodied energy and carbon emissions will also be useful for incorporating waste as a design factor in the early phases. Table 3 shows energy and carbon emissions produced through the core construction material.

Table 3 Embodied Carbon Emission for Significant Material.

Construction material	CO ₂	Unit
Cement	630	Kg/ton
Steel	1880	Kg/ton
Aluminum	56	Kg/ton
Concrete -Ready Mix C20 & C35 Excluding Cement manufacturing factor	4.95	Kg/ton
Concrete block Excluding Cement manufacturing factor	4.32	Kg/M ³
Brick	440	Kg/ton
Mortar and wood	9	Kg/M ³
Electricity	231	Kg/MWh
Transportation by truck	0.106	Kg/Ton-Km
Concrete Transportation (Mixer)	0.153	Kg/Ton-Km

3.2. Phase 2 Processing and Logistics

In this stage, the study is trying to analyze and collect the energy that is consumed during the manufacturing process for each of the final prepared construction materials, such as concrete, block, concrete reinforced concrete etc. The method of this calculation will be obtained from collecting all direct and indirect carbon emissions released and energy consumed for each of:

- Manufacturing the core material that is analyzed within phase 1.
- Transportation and other services.
- Electrical and heating usage.

The table below presents the carbon footprint for the significant construction material.

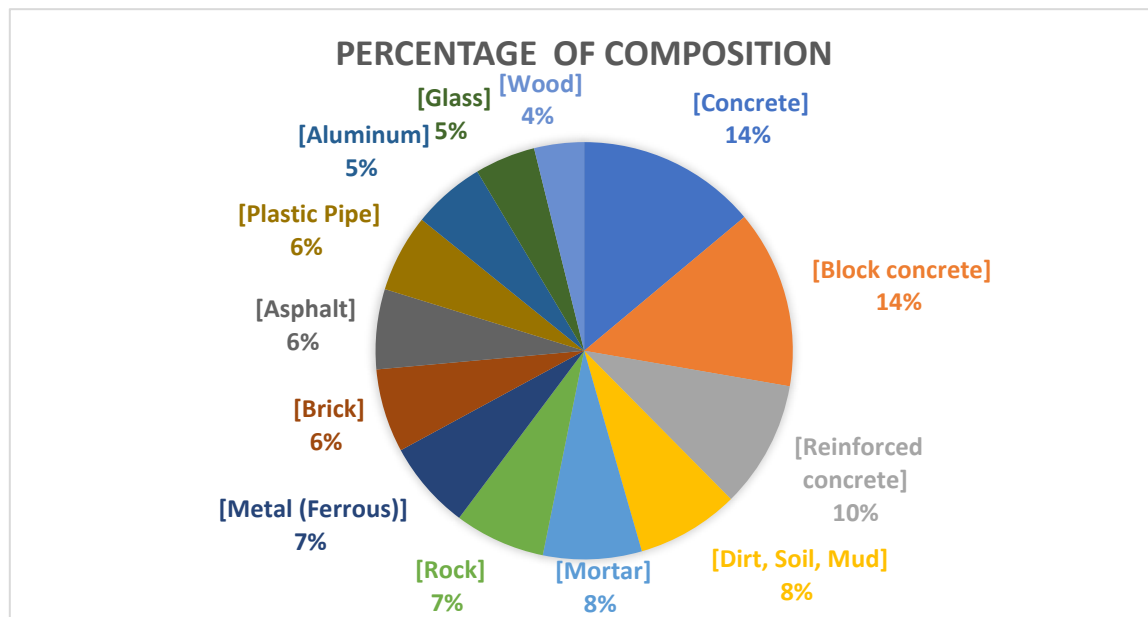
Table 4 Carbon Emission for Producing Construction Direct Construction Material.

Carbon emission CO ₂ in Kg per ton of concrete	
Production process	CO ₂ in Kg per ton of concrete
Production and transport of fine aggregates	4.32
Cement for concrete C25 or C35	105
Transport Cement to Erbil RMX plant	16.96
Concrete production at RMX	4.95
Total	131.4
Carbon emission CO ₂ in Kg per ton of block concrete	
Total	130.8
Carbon emission CO ₂ in Kg per ton of Reinforced concrete	
Production and transport of fine aggregates	1.05
Cement for concrete C25 or C35	105
Transport Cement to Erbil RMX plant	16.96
Concrete production at RMX	4.95
Thumb rule for steel in slab = 2%	295.16
Total for 1 M ³	423.3
Total for one ton	169.3
Carbon emission CO ₂ in Kg per ton of asphalt	
Virgin mix	14.51
Transport the raw material	5.3
Heating and missing	15.6
Total	35.41

3.3.Phase 3 Questionnaire Survey for Contributed Waste Material

Waste construction material and composition can vary from project to project. Due to the uncertainty of waste volume during domestic construction projects, practical data were gathered by distributing questionnaires to project site engineers and managers in Erbil city. Twenty-nine responses were obtained from thirty-four distributed questionnaires, all

of which were supervised or managed construction and road projects. The survey analysis showed that excess concrete, broken block concrete, demolished reinforcement concrete, and excavation dirt are materials that can have a high ratio of construction waste. The estimated ratio for other access building materials that can be found in domestic construction is shown in Fig. 1 below.

**Fig. 1** Ratio of Estimated Material Contained within Waste Construction.

4.RESULTS AND DISCUSSION

4.1.Quantity of Carbon Emissions

Based on the composition of waste materials obtained via a distributed questionnaire survey, these materials can be linked to the quantity of carbon emissions for each item, which led to obtaining the total CO₂ emissions for one ton of construction waste. A total of seventy-five% of respondents had experience with new domestic construction projects in Erbil city. Few construction companies prioritize waste

management. They cite several factors that contribute to the waste volume, including design mistakes, insufficient supervision, and overestimated quantities. Most construction contractors and industry need to pay closer attention to waste management in building construction and unify their sorting and recycling protocols. The result shows items like concrete and reinforced concrete, which have a similar manufacturing method but differ by 24% in carbon emissions. This comes from

containing material that required high energy during the manufacturing process, which represented Iron and steel. The energy consumed in excavation and rock-digging during site preparation and leveling is ignored.

4.2. CO₂ Emissions and Construction Waste Materials

The results in Table 5 show the largest emission material for access metal, brick, and concrete. The measurement was taken either directly via a gas analyzer for heavy oil fuel or calculated the aggregate amount using a flow meter and converted the thermal power accordingly to obtain the carbon emissions. The composition of the disposed material can be categorized into several groups. These include materials derived from heavy industrial processes, such as steel,

cement, and brick manufacturing, which account for the largest proportion of CO₂ emissions, estimated at 210.7 out of 218.4 kg of CO₂ per ton. Efforts are implemented in Iraq to recycle debris from these industries, such as recycling steel waste. Additionally, significant initiatives are focused on reusing waste from the cement production process. Some of these efforts are managed by plants that belong to European organizations, aiming to reduce CO₂ emissions from 630 kg to 420 kg by the end of 2030. Their strategy involves collecting waste, processing it through crushers, and integrating it into production processes, which has shown a notable impact on achieving their CO₂ reduction targets [22].

Table 5 Carbon Emission for One Cubic Meter of Waste.

Composition of waste material	Percentage of composition	Benchmark CO ₂ Kg/ton	Construction waste CO ₂ Kg/ton
[Concrete]	13.9%	131.4	18.3
[Block concrete]	13.8%	130.8	18.1
[Reinforced concrete]	9.9%	169.3	16.7
[Dirt, Soil, Mud]	8.0%		0.0
[Mortar]	7.6%	9	0.7
[Rock]	7.0%		0.0
[Metal (Ferrous)]	6.9%	1880	129.1
[Brick]	6.5%	440	28.5
[Asphalt]	6.2%	35.41	2.2
[Plastic Pipe]	6.0%	8.06	0.5
[Aluminum]	5.6%	56	3.2
[Glass]	4.7%	19.1	0.9
[Wood]	3.9%	9	0.3
Sub Total	100.0%		218.4
Landfill transportation and collecting			5.3
Total			223.7

4.3. Transportation Energy Consumption

Energy consumption that comes from transportation and logistics is a stochastic value that varies for several reasons, such as:

- The location from the cement and steel plant to the site mix concrete or steel workshop. For Example, 153 km was the calculated average distance to deliver cement to the ready-mix location in Erbil from five main cement plants (four in Sulaymaniyah and one in Erbil). This distance led to an addition of 16.2 Kg CO₂/Ton to the concrete carbon emission credit.
- The calculations are based on the average fuel consumption of different mixer vehicles, considering their average load capacity in cubic meters. This value is then divided by the average distance between the ready-mix concrete (RMX) plant and the project site where the material is unloaded.
- Notable progress has been observed in logistics decarbonization, with significant attention from some Iraqi RMX plants. This is particularly important as traditional fuel-powered trucks are among the highest contributors to CO₂ emissions.

The logistics journey from the site mix concrete or steel workshop or warehouse to the project location also has its own merit value that needs

to be considered in terms of energy consumption. Neglect the carbon release impact for each of Dirt, Mud and Rock during excavation due to planning and reusing them within the same site or filling low-level areas next to the construction project area.

4.4. Factory Generator Carbon Emissions

Operations of small factories are run on the national grid, which calculates and accounts for their CO₂ emissions (231 Kg CO₂/kWh). During a grid blackout, they are operating a diesel generator that emits 708.9 kg CO₂/ton. The value contributes 50% to gas exhaust for all construction materials produced in small factories. Most factories are situated in rural areas where power outages average about 12 hours per day. This significantly affects CO₂ emissions per ton of production.

5. CONCLUSIONS

This study aims to investigate energy consumption associated with domestic construction waste, which can be used as sustainable method for treating and recycling waste. Analysis of the distributed questionnaire found that little attention and interest were paid to the embodied energy of prefabricated materials, and less emphasis was placed on low-carbon materials. The inventory of building materials and carbon emissions has been

synthesized for Kurdistan and the Iraqi region, which are mostly correlated with economic factors and primary energy cost in this area. Steel, cement, and brick have the highest embodied energy, accounting for 93% of construction materials. The absence of an effective execution framework, primarily due to inadequate design and insufficient supervision, is a key factor contributing to the volume of construction waste. This knowledge and data can be applied to calculate the embodied energy for domestic and commercial buildings and select a more suitable material for low-carbon buildings during the design phase. The main limitation was a lack of information on domestic construction history and the volume of waste material buried and transferred to the landfill. As a recommendation for future, this study could be extended to analyze carbon dioxide emissions from other infrastructure and industrial projects. In addition, it can consider the life cycle of other minor materials used in these sectors.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Gzing Adil Mohammed and Farah Subhi H.: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. *Shuokr Qarani Aziz and Dilshad K. Jaf:* review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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NOMENCLATURE

LCA	Life Cycle Assessment
CO ₂	Carbon Dioxide
KRG	Kurdistan Region
CO	Carbon Monoxide
SO _x	Sulfur Oxides
NO _x	Nitrogen Oxides
TOC _s	Total Organic Carbon
VOC _s	Volatile Organic Compounds
CaCO ₃	Calcium Carbonate
C&D	Construction and Demolition

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