Carbon Emissions from Construction in China

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Contributor: Mukhtar A. Kassem, li xiaojuan, Chen Wang, Taibing Wei

The construction industry's high energy consumption and carbon emissions significantly burden the ecological environment. Numerous solid wastes and greenhouse gases (GHG) are generated as high-energy-consuming and high-emission products during the construction process. Thirty percent of China's total energy consumption comes from construction projects.

Keywords: construction industry ; life-cycle assessment (LCA) ; carbon-footprint calculation

1. Introduction

Numerous solid wastes and greenhouse gases (GHG) are generated as high-energy-consuming and high-emission products during the construction process. Thirty percent of China's total energy consumption comes from construction projects [1]. Construction activities account for around 40% of the total natural resources and energy consumed by human beings, representing approximately 40% of total solid waste [2]. Most previous studies regarding building carbon footprints focused on the operation stage of the building rather than the construction delivery stage [3]. The accuracy and completeness of calculations at each stage need further improvement [4]. The construction delivery stage uses various materials, construction machinery, and transportation equipment, resulting in a large amount of carbon dioxide (CO_2) [5]. The energy and materials used during the delivery stage of construction exhibit the characteristics of concentrated and absolute emissions [6].

2. Carbon Footprint Life-Cycle Assessment

2.1. Carbon Emissions from Construction

Several calculation methods are usually used for carbon-emission calculation, where the measurement method uses specific, approved standards or instruments to measure the concentration, flow rate, and footprint path. The inputs and outputs must be comprehensively analyzed [7], and such a work process is complex and time-consuming [8]. The emission-coefficient method calculates the total footprints based on the average value of the quantity of emitted gas [9]. The carbon-emission coefficient method is relatively simple, straightforward, and easy to understand; it is based on activity data and carbon-emission coefficients. However, it is also relatively extensive when compared with other methods. Therefore, the carbon-emission coefficient method was selected to calculate the carbon emissions during the building phase.

Several studies combining carbon footprints have also already been conducted. In this context, the case determine the boundary range of carbon footprints and the correlation between energy and carbon share embodied in different levels of building energy efficiency [2]. Moreover, these cases can correlate building energy consumption and carbon emissions [10] and verify reductions in building energy consumption and carbon emissions using a scientific construction-management system [11]. Different structural methods calculate energy consumption and carbon emissions, such as LCA [12]. A carbon-emission calculation model [13] has been established, and identification shows that energy, building materials, and machinery are the primary carbon-emission sources [14]. A carbon-emission law is established and analyzed according to the influence of base cost on carbon emissions [1]. Energy consumption and carbon emission for different building materials can be analyzed in building components in the production, transportation, and installation phases [15]. Scholars [1][16] proposed an accurate calculation of the carbon emissions from precast concrete piles during their construction process using the LCA theory combined with an energy-analysis tool. At present, the analysis methods for determining the factors influencing building carbon emissions include ecological emission [17], the logarithmic mean divisia index decomposition method [18], and emission intensity [19]. Research indicates that emission intensity is the largest share of carbon-emission factors in the construction industry.

Research on carbon footprints in the construction field is mainly based on data from international organizations or foreign institutions. Buildings are divided into detailed stages, and their total carbon footprints are obtained using the carbon-emission calculation method. However, a construction period of two to five years for projects can be regarded as a micro life cycle [20], and studying the carbon footprint in detail is extremely necessary. Previous studies generally considered that the construction-operation phase caused many emissions, and the construction-operation period occupied most of its entire life cycle [21]. Therefore, the evaluation period significantly affected the evaluation results. The literature mentioned above did not consider emission reduction in the construction process due to construction scale, design period, and construction period. On the other hand, it calculated carbon emissions per unit construction area per year. As a result, it obtained comparable calculation results, which guided the optimization of the construction-material production process, transportation, construction, and waste disposal during the construction delivery stage.

2.2. Basic Issues of Carbon Footprints during Construction

2.2.1. Types of GHG and Their Measurement Units

GHG in the atmosphere mainly include CO_2, water vapor, methane (CH_4), nitrous oxide (N_2O), ozone (O_3), fluorochlorocarbons (CFC_S), hydrofluorocarbons (HFC_s), perfluorocarbons (PFC_s), hydrochlorofluorocarbons ($HCFC_s$), and sulfur hexafluoride (SF_6) [22]. The sources of GHG emissions can be divided into natural sources (including gases such as CO_2, CH_4, N_2O, and O_3) and anthropogenic sources (including CFC_s, HFC_s, PFC_s, and SF_6) [23]. According to the decision at the Montreal Convention, chlorofluorocarbons (CFC_s) have been banned, while CO_2, N_2O, CH_4 have been left and kept as the main three gases from GHG that cause increased temperature; this is presented in the Intergovernmental Panel on Climate Change (IPCC) evaluation report.

Global warming potential (GWP) is a unit of measurement that assesses the degree of the effects that GHG have on global warming, i.e., a certain period in which the degree of a certain GHG affects global warming per unit mass is converted into an equivalent effect caused by the same quality of CO_2 using a relevant conversion value [24]. Following the IPCC inventory guidelines for GWP, CO_2 GWP is set to a standard value of one, and those for other GHG are obtained differently [1]. The same conversion rules can be used to obtain the CO_2 equivalent to other GHG.

2.2.2. International Carbon-Emission Accounting Standards

At the accounting level, the PAS 2050 specification is suitable for calculating CO_2 emissions from different life-cycle periods at different stages. Therefore, this study refers to the PAS 2050 specification to define carbon emission limits, determine the source of carbon emissions, and develop an accounting model. The PAS 2050 specification clearly defines the system limits of carbon emissions, carbon sources related to products within the system limits, information, and accounting methods required to perform accounting. The calculation system determines that activity-level data and emission factors are two types of information necessary to calculate carbon emissions. The formula provided by IPCC to calculate the amount of carbon emissions is the same. The system limits are divided into nine parts: energy, raw materials, use, facility operation, transportation, storage, asset commodities, manufacturing and service provision, and final disposal [25].

2.3. Determination of Carbon-Emission Factors for Building Materials

2.3.1. Semifinished Materials

Sand and gravel are basic materials used in building construction. A study of the literature reveals that different scholars have calculated sand and gravel carbon emission factors in different ways [26][27]. The carbon-emission factors of sand and gravel are then calculated. A literature search found that the average electricity consumption per cubic meter of sand is 1.32 kW·h, and fuel oil is 0.76 kg [26]. The packing density of sand is 1450 kg/m^3, and gravel is 1560 kg/m^3 [9]. Subsequently, the sand and gravel carbon-emission factor is computed by combining the carbon-emission factor of electricity and fuel oil. The calculation formula is expressed as sand carbon emissions: $1.32 \times 1.01 + 0.76 \times 3.9 = 4.297$ (kg/m^3); sand: $(1.32 \times 1.01 + 0.76 \times 3.90)/1.45 = 2.964$ (kg/t); and stone: $(1.32 \times 1.01 + 0.76 \times 3.90)/1.56 = 2.755$ (kg/t).

2.3.2. Steel

Steel is an indispensable main building material used in construction projects. The amount of carbon emission from steel exhibits a clear relationship with manufacturing technology. Most of the CO_2 emitted during steel production is from fuel and energy usage. Although the carbon-emission coefficient of steel in all construction materials is high, steel should be considered for recovery. However, steel recovery in reinforced concrete is relatively difficult, and the recovery rate is only 0.5. Therefore, a higher recovery rate of 0.9 is chosen for steel molds and section steel. **Table 1** and **Table 2** list the carbon-emission factors of various types of steel under different recovery rates.

Table 1. Steel carbon-emission coefficients under different recycling conditions (kgCO_2/kg).

Recovery Rate	Large-Scale Steel	Small- and Medium-Sized Steel	Hot-Rolled Steel Bar	Cold-Rolled Steel Bar
0	**3.744**	**3.003**	**3.154**	**3.938**
10%	**3.519**	**2.823**	**2.965**	**3.702**
20%	**3.295**	**2.643**	**2.766**	**3.465**
30%	**3.07**	**2.462**	**2.586**	**3.229**
40%	**2.845**	**2.282**	**2.397**	**2.993**
50%	**2.621**	**2.102**	**2.208**	**2.757**

Recovery Rate	Large-Scale Steel	Small- and Medium-Sized Steel	Hot-Rolled Steel Bar	Cold-Rolled Steel Bar
60%	2.396	1.922	2.019	2.52
70%	2.172	1.742	1.829	2.284
80%	1.947	1.562	1.64	2.048
90%	1.722	1.381	1.451	1.811
100%	1.498	1.201	1.262	1.575

Table 2. Carbon-emission factors of four types of steel.

Building Material Name	Unit	Carbon-Emission Factor $kgCO_2/kg$			Scope of Application
		90%	50%	0%	
Large steel	kg	1.722	-	3.744	Section steel
Small and medium steel	kg	1.382	-	3.003	Angle steel, flat steel, steel formwork, Steel bracket, etc.
Hot-rolled strip	kg	-	2.757	3.154	Cold drawn steel wire
Cold-rolled strip	kg	-	2.208	3.938	Rebar, round steel

2.4. Carbon-Emission Factors of Some Decoration Materials

2.4.1. Water-Discharge Factor

The average water resource allocated to most people is 2300 m^3, which is only approximately one-fourth of the global per capita level. These data show that, relatively speaking, China lacks water resources. Construction projects consume a large amount of water during the delivery stage. The production and preparation of tap water consumes less energy, and most of the energy is consumed in transporting water. According to research [4][12], the value of the water-discharge factor is 0.91 kg/m^3.

2.4.2. Wood

Wood is a green and environmentally friendly material with carbon fixation. Some countries combine the carbon sequestration function of wood. Thus, the calculated carbon-emission coefficient is negative. Considering the actual situation, in which the ecological value of wood has not been reasonably utilized because of the random logging of forest resources in China, the situation is most unfavorable when the carbon fixation function of wood is considered [27]. The carbon-emission factor of wood is 73.9 $kgCO_2/m^3$.

2.5. Carbon-Emission Factors of Construction Machinery

The carbon-emission factor of mechanical equipment during the construction delivery stage can be obtained by calculating the amount of fuel consumed by the construction machinery unit and the carbon-emission factor of the fuel at this stage [28]. Electricity is the main energy used by construction machinery and equipment. The carbon emission of fuel is combined with the emissions of the three stages of production, transportation, and combustion [29]. The formula for calculating the carbon-emission factor of mechanical equipment is

$$C = 3.99 \times M_\alpha + 3.94 \times M_\beta + 1.01 \times M_\gamma \quad (1)$$

where M_α , M_β and M_γ are the mechanical equipment's diesel, gasoline, and electricity consumed during the construction process.

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