

Carbon Emission of Construction Materials and Reduction Strategy: Take Prefabricated Construction in China as an example

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Abstract. The rapid development of urbanization has made the building industry gradually become a major industry of carbon emissions. Now that the goal of carbon neutrality is increasingly clear, the construction industry will face a very serious challenge of energy conservation and emission reduction. Especially in developing countries, such as China, to achieve carbon neutrality, the government pay more attention to emission reduction and environmental protection in the construction materials industry. This paper first analyzes the carbon emissions of three common building materials: cement, steel, and asphalt. The production of one ton of cement will produce about 659 kg of CO₂; the production of 1 ton of crude steel will produce more than 2,000 kg CO₂, and the construction of a 20 km long road will produce more than 50 million kg of CO₂. To achieve carbon emission reduction in the construction process and alleviate the pressure on the environment, prefabricated buildings are an important carbon reduction strategy. Compared to on-site construction, prefabricated constructions use less resources and release less carbon dioxide. However, prefabricated construction technology is not the mainstream of the construction domain yet in China. The paper analyzes the factors of the growth of prefabricated construction from three aspects: society and government, market, and technology.

Keywords: Carbon Emission, Prefabricated Construction, Construction Materials, Peak Carbon Dioxide Emissions.

1. Introduction

Over the past century, population growth has led to rapid urbanization and industrialization, and pressure on natural resources has been unprecedentedly increased. In 1992, the United Nations first proposed the concept of sustainable development at the "Environment and Development" conference in Brazil. The goal is to find that environmental quality and environmental inputs play a pivotal role in people's income and improved quality of life. The construction industry has grown extremely rapidly in recent years, especially the developing countries of East and South Asia. At the same time, the construction industry is also the industry with the greatest impact on the environment. Building Construction consumes enormous amounts of energy through the life cycle and is the leading industry contributing the largest carbon emission. About forty percent of sands, a quarter of raw wood and sixteen percent of water are consumed by the construction industry each year. The building industry consumes over 40% of the world's resources every year to meet the huge demands of production, which brings 33% of global greenhouse gas emissions in the meantime [1]. To achieve the goal of carbon peaking and carbon neutrality, the realization of sustainable idea requires the control of carbon emissions from construction. Cement is one of the important construction materials, and the carbon dioxide emission mainly comes from the clinker production process. Carbon emissions from cement production are 6% of global anthropogenic carbon emissions. The construction industry consumes a large amount of steel every year, which also contributes to its high carbon emissions, accounting for 6.7% of the total global emissions from steel [2].

Past studies have analyzed the sources of carbon emissions during the construction, but studies have not fully focused on carbon emissions during the construction phase. For example, some analyses of greenhouse gas emissions only focus on the carbon emissions produced by construction materials; some focus on the manufacture process of raw materials; some pay more attention to the

transportation of building materials. The common emission reduction solutions are the use of sustainable building materials to replace traditional materials and develop the prefabricated construction.

The purpose of this paper is to analyze the carbon emissions of different building materials during production, and to study prefab buildings in China as an example. The specific objective is to analyze the carbon emissions caused by direct emission pathways of these three common building materials: cement, steel, asphalt; carbon reduction capacity of prefab buildings and all kinds of the influencing factors.

2. Carbon Emission from Construction Materials

Construction materials are divided into different stages from production to site use, and each stage will have certain carbon emissions. Starting with the production and transport of building materials, these stages is 82-96% of the total emissions from the entire construction process [3]. Figure 1 shows the proportion of carbon emissions at different construction stages. A study showed that Nanjing's carbon footprint expanded quickly from $263.66 \times 104 \text{ hm}^2$ in 2009 to $719.08 \times 104 \text{ hm}^2$ in 2020, nearly half of which came from the construction industry [4]. This shows that as time goes by, developing countries like China, which attach importance to infrastructure construction, will use more building materials to achieve their development goals, which will inevitably lead to more carbon emissions.

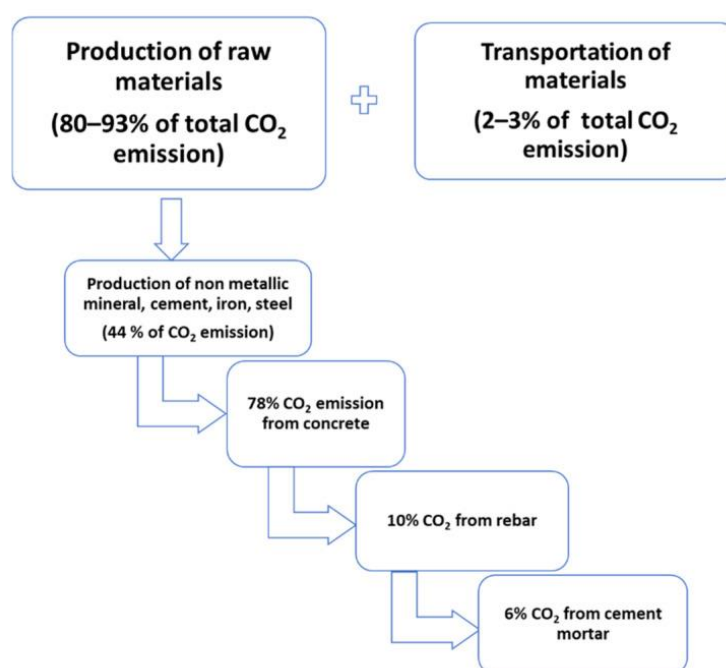


Figure 1. Carbon emissions at separate phases of construction

2.1. Cement

Cement is mixed with water and aggregates to make concrete. The main component of cement is cement clinker, which is obtained by calcining rocks rich in limestone and clay. Two-thirds of the waste gas emitted from cement is produced during the chemical reactions that take place in the production of clinker, and one-third comes from greenhouse gases emitted from the fossil fuels used to heat the furnaces to calcine the rock. Limestone is a common carbonate sedimentary rock. To produce cement, huge amounts of limestone need to be decomposed, and in the process a significant amount of carbon dioxide are released. Limestone consists mainly of calcium carbonate and some other carbonates. Chemical equations (1) and (2) represent the decomposition process of limestone, which can be used to calculate the emissions of CO_2 .



Limestone usually contains 65% CaCO_3 , according to chemical equation (1), every kilogram of CaCO_3 consumed will produce 0.44kg of CO_2 . Thus, in the manufacture of cement, 0.286kg of carbon dioxide is produced in the stage of decomposing limestone. About 15 grams of each kilogram of limestone is magnesium carbonate. Similarly, according to chemical equation (2), we can obtain that 0.0078kg of carbon dioxide is released when magnesium carbonate is decomposed. Finally, adding the carbon dioxide emissions from the two stages, we can calculate that for every 1kg of cement produced, 0.2938 kg of carbon dioxide gas will be emitted.

Cement production currently accounts for about 7.4% of global carbon CO_2 , with an estimated 2.9 tons of CO_2 coming from the cement industry in 2016 [5]. The cement industry's carbon reduction mission also deservedly plays a significant role in global warming. One Chinese study shows that in the construction of cement concrete pavement, the final emission of CO_2 is 8215.31 tons per kilometer [6]. The research team presents a list of greenhouse gas emissions from 1 ton of cement production, depending on the consumption of coal, diesel and electricity. Table 1 is the greenhouse gas emissions in the manufacture of cement.

Table 1. Greenhouse gas emissions in the manufacture of cement [6]

Energy Consumption / ton of cement			Emission / ton of cement		
Coal	Diesel	Electricity	CO_2	N_2O	CO_2e
116kg	0.20L	97.4KWh	1.33kg	1.60kg	162.50kg

2.2. Steel

The materialization of steel includes two stages: raw material extraction and steel production. Blast furnace ironmaking is to melt iron ore and coke in the blast furnace, so that the reduction reaction occurs at high temperature. What is reduced from iron oxide is pig iron, which is mostly iron and contains a small amount of carbon. Steelmaking produces carbon dioxide at multiple stages, especially blast furnaces that need to be heated above 1,000 degrees Celsius in order to extract iron from the ore. Global steel production reached 1,689 tons in 2017. The intensity of carbon dioxide produced by steelmaking varies from country to country because of different manufacturing processes and other factors. Germany produces 1,708kg CO_2 for every ton of crude steel. When the America Steel industry manufactured one tone of crude steel, 1,736kg CO_2 is produced. By comparison, China produces more CO_2 per ton of crude steel, at 2,148kg. [7]. According to World Steel Association's calculations, steel manufacturing accounts for about 8% of carbon dioxide emissions, which makes the steel has become one of the world's largest carbon emitting building materials industries [8].

2.3. Asphalt

The vast majority of refined asphalt is widely used in the construction industry, of which 70% is used for road construction, including highways, airport runways, sidewalks, etc.; another 10% is used for roof waterproofing [9]. Asphalt is a viscous, black, semi-solid form of petroleum used to bind aggregates together. Constructing an asphalt road usually includes 4 stages: mixture, transportation, paving and compaction. Among them, mixing is the step with the most carbon emissions. In many projects, the method of increasing the discharge temperature of the mixture is often used to ensure the working capacity of the mixture, but such a construction method will increase carbon emissions. According to the study of Ma et al., the CO_2 emission in the construction of twenty kilometers asphalt road is 52,264,916.06kg [10]. Table 2 shows the amount of CO_2 produced at different stages when asphalt pavement is constructed.

Table 2. CO_2 emissions in different phases [10]

Mixing	Transportation	Paving	Compacting
4,927,045.97kg	123,394.56kg	78,015.18kg	55,658.37kg

3. Analysis of Emission Reduction Methods

According to a report released by the World Resources Institute, the total number of countries that have peaked or committed to peak by 2030 reaches 57. As the concept of sustainable development has been paid more and more attention by various countries, many studies have tried to find methods and strategies to reduce the emissions of carbon dioxide in the construction process. In the context of building green transformation and upgrading, stakeholders in the industry are actively trying to control the growth of carbon emissions. These studies are divided into two types: one is to seek new materials to replace traditional materials to reduce carbon emissions, which includes the usage of recyclable materials to improve the multiple use rate of materials; another type is to design, change construction methods and other methods, continue to use traditional materials to save energy and reduce emissions. This article will analyze the impact of using prefabricated construction methods on energy conservation and emission reduction and the factors that affect its development.

3.1. Prefabricated Construction

Prefabricated buildings transfer so many on-site works from construction site to the factories where they are assembled and installed on site through reliable connections. Because the use of standardized and intelligent design, it is the representative of modern industrial production method. Prefabricated structures have been widely praised for their low environmental impact and higher construction efficiency and have become a more popular construction technology today. The quantities of raw materials used to manufacture the product meet specific project requirements, resulting in the completion of the task with minimal waste. Thus, the process of creating components becomes energy efficient and sustainable. Several studies have also confirmed that prefabricated buildings can reduce the carbon emission in the construction field.

Prefabricated construction is an energy-saving and sustainable construction method. Traditional construction often results in a lot of extra material waste. Factory prefabrication allows for more precise determination of production quantities, and additional material is recycled on the spot and awaits reuse. According to the standard design, the manufacturer can determine the number of assemblies in advance. Through the optimization process, the problem of material waste in site construction is avoided and the transportation cost would be saved. These can improve energy efficiency. According to the conclusions drawn by Cao et al., compared with on-site construction, prefabricated buildings reduce resource consumption by 35.82% and the impact on the ecosystem was reduced by 3.47% [11]. A research team built a model based on construction literature and empirical data to evaluate the environmental impact of prefab buildings, then it concluded that prefab buildings could reduce CO₂ emissions by 20% [12]. Another important advantage is that prefabricated buildings can save money. The capital cost can be reduced by ten percent by using a modular structure. Another study found that offsite construction provides up to 30% cost-effectiveness [13]. Under favorable conditions of transportation, assembly, weather, etc., prefabrication can reduce a lot of time compared to site casting construction because different parts can be produced simultaneously. This also depends on good engineering management and the supply efficiency of various stakeholders in the supply chain. Since construction firms are more productive as a result, firms are in theory better able to stimulate capital turnover and a virtuous cycle.

3.2. Influence Factors

Many factors will affect the carbon reduction capacity and growth of prefab building. This paper will analyze the factors impacting on the growth of the prefab construction in China, including government factors, marketing factors, technology factors and so on.

3.2.1 Social and Government Factors

The Chinese government is aware of environmental concerns and has an interest in pushing prefabricated buildings steadily forward. Although the increasing number of prefab buildings in China, the industry is still in its initial stage. The construction industry is a major pillar industry in

China, accounting for more than 6.9% of the GDP. In 2020, the housing construction area was 14.947 billion square meters. China government issued a bunch of policies and suggestions such as the “13th Five-Year Plan for Prefabricated Building Construction”. In addition, the “14th Five-Year Construction Industry Development” issued by the Ministry of Housing and Urban-Rural Development of China clearly mentioned the vigorous development of prefabricated buildings. It is planned that by 2025, Prefab construction will reach more than three-tenths of the market share [14].

Government regulation and constraints are also an important factor. The government has restricted the high-carbon development of prefabricated buildings by enacting various policies, such as cap-and-trade schemes and carbon taxes. Take the U.S., the government emphasizes four categories of policies about carbon emission: mandatory carbon emission capacity, carbon tax trade, and carbon offset investment. Taxes and caps are early signals of greater attention to regulating carbon emissions, and these have an effective impact on carbon reductions in supply chains. If these become the future direction of the Chinese government's consideration, it may promote the green transformation of the construction industry.

3.2.2 Market Factors

Corporate low carbon awareness may also drive the entire construction industry to play a role in the reducing carbon emissions. The market environment will have a profound impact on companies' research on low-carbon buildings, especially their low-carbon awareness. According to the results of field interviews, the promotion of low-carbon technologies by enterprises largely depends on whether consumers agree [15]. However, the development of prefabricated buildings in China still lags far behind traditional buildings. Technical barriers and cost control of low-carbon buildings make it difficult for companies to continue to promote in the current construction market. In addition, low carbonization will also be a long-term marketing strategy, which also means that consumers' low carbon awareness will change the low-carbon behavior of enterprises, urging the latter's green transformation and upgrading. Appropriate marketing strategies are able to disseminate information about new technologies, enhance the attention from the potential customers, subtly improve users' understanding of low-carbon awareness, and boost the growth and application of new construction technology. A forward-looking, long-term planning approach that will achieve sustainable competitive advantage [16].

3.2.3 Technology Factors

Technical factors may be the most direct factors affecting the development of low carbonization of prefabricated buildings. Although prefabricated buildings claim to reduce resource consumption and carbon emissions, the carbon emissions during the production and use of raw materials are still high. Low-carbon and sustainable production of raw materials and assemblies will receive fewer inputs and lower emissions. At the same time, the improvement of recycling level will also promote sustainable development to a certain degree. The cost of applying low-carbon technologies is also a key consideration for businesses, and economic benefits are a major consideration for all firms involved in the entire process. The cost of prefab components is relatively high. The standardized design and mechanized operation of prefab buildings in China are low, the modules are not unified, and the production cannot be mass produced, resulting in a higher cost than the cost of cast-in-place construction. Construction technology training is insufficient, workers do not have sufficient operating conditions. The industrial supporting chain is not perfect, and the management mode has not formed effective coordination. It is necessary to fully enhance the stability and maturity of the prefab building structure, optimize the low-carbon and green design, and improve the confidence of the market and the government in supporting the industry.

4. Conclusion

The significant amount of carbon emission during the construction is a big challenge to deal with environmental protection today. This paper studies the carbon emissions from the production process

and construction process of building materials. The government and social organizations have realized the huge problem of carbon emissions in the construction industry and have introduced various measures and emission reduction strategies to deal with it. As a new type of environment-friendly construction method, prefabricated buildings will effectively reduce resource consumption and carbon emissions. Prefabricated buildings reduce carbon dioxide by 20%. To research the factors that impact the emission reduction of prefab buildings, this paper analyzes from three aspects: society and government, market, and technology. In terms of policy, the government generally has a positive attitude towards it, and has introduced various measures to encourage and promote it; in the market, companies need to improve their marketing strategies for prefabricated buildings; in terms of technology, companies need to break barriers and continue to promote technology to improve efficiency. Prefabricated buildings are only an emission reduction strategy in terms of construction methods and can also promote carbon reduction in many aspects such as transportation, equipment energy consumption, and structural design. In addition, researching new building materials to reduce carbon emissions is also an emission reduction method, such as the application of recycled aggregates, composite fiber cement soil, etc., which will be our main consideration in the future. With innovations in materials and construction techniques, other suitable solutions will emerge, also considering further conditions.

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