ASSESSMENT ON THE CARBON EFFICIENCY IN THE CONSTRUCTION STAGE: A COMPARATIVE STUDY BETWEEN PREFABRICATED AND CONVENTIONAL CONSTRUCTION

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Abstract. *Construction industry is the consuming large amounts of natural resources and at the expense of a heavy environmental burden. Therefore, we need to keep a balance between creating economic benefit through construction and focusing on the influence to the environment with the aim of the value of carbon emissions maximize. The paper puts forward carbon efficiency which provides a linkage between carbon reduction and value creation of construction effectively can reflect construction efficiency. The essence of carbon efficiency is using the lowest environment output to build a construction. Through analysing two cases, result shows that carbon efficiency of prefabricated construction is higher than the conventional construction's, which improves 25%. Besides, the measures are provided to improve the carbon efficiency of constructing. Enhancing the precast level, implementing prefabricated components standardized, optimizing site management is the main key to realize the low carbon construction.*

Keywords: Carbon efficiency, Prefabricated construction, Construction method, Carbon emissions.

1 INTRODUCTION

At the present days, climate warming has been concerned all over the world. The fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicated that after the industrial revolution, the increase of carbon in the atmosphere caused by the industrialization of human society was the main driving force of climate change [1]. The building and construction sector is one of the three dominant sectors that greatly consumes energy, which its construction activities are closely related to the greenhouse gas emissions. In China, construction energy consumption accounts for 27% of total energy consumption, and carbon emissions account for about 40% of total emissions. Besides, due to the process of urbanization which will last 25 to 30 years, the scale of urban construction in China has been growing at a rate of 5% to 8%, which accounts for 40% of the construction in the world [2]. Therefore, construction energy consumption and carbon emissions are the key issues of the current research.

Prefabricated construction is well used in the construction activities, with the government calling for the low-carbon economy and low-carbon construction. Prefabricated construction within manufacturing is characterized as design standardization, prefabricated components made in factory, construction mechanization and scientific organization and management [3]. There are a huge improvement in the aspects of effective allocation of resources and speed of on-site assembly. Most researchers insist the opinion that prefabricated construction is more energy-efficient than conventional cast in-situ construction. Prefabricated construction is an effective way to achieve low-carbon construction in the construction industry.

However, previous studies focused on calculating the absolute carbon emissions and make a compare between prefabricated construction and conventional construction. The conclusion is always made that prefabricated construction has less carbon emissions. Obviously, it's not scientific and accurate for comparing the prefabricated construction and conventional just depends the result of the absolute carbon

emission calculation. For example, the construction area, construction scale and speed of construction all have a great impact on carbon emissions. Hence, the research can't just rely on the carbon emissions to compare and analyse. The paper put forward the concept of carbon efficiency on the basis of calculation carbon emissions of two construction methods. The essence of carbon efficiency is evaluating the value of carbon emissions from the view of construction efficiency and estimating whether the construction carbon output achieve the value maximize. At a word, the higher construction efficiency, the lower carbon emissions, means the higher carbon efficiency. Such a way of construction is essentially low-carbon construction.

2 LITERATURE REVIEW

2.1 Calculation methods of construction carbon emissions

In recent years, there is a wide variety of the researches of calculation methods of construction carbon emissions. There are four main methods are used frequently in calculating construction carbon emissions [4]. The first method is industrial interrelations matrix analysis. This method mainly based on the content of the industrial interrelations matrix, calculating the direct or indirect effect of product value between the building materials industry and energy industry on the basis of the demand of construction industry and the consumption of building materials. Then calculate the carbon emissions. The advantages of this method is it can calculate through amount and it's easy to convert into carbon emission. The disadvantages of this method is it includes lots of indirect effect factors, causing the result inaccurate. The second method is input-output method. In this method, the direct carbon emission coefficient of the relevant construction departments is combined with economic input-output table, and obtain the direct and indirect carbon emissions by using the input-output model. The advantages of this method is it can combine various data of different departments and obtain the direct and indirect carbon emissions. The disadvantages of this method is it's difficult to collect too much data because of the extensive data sources. The third method is measure method. The content of this method is to estimate the carbon emissions by measuring the actual occurrence of all kinds of gas emissions within the established boundary. The advantages of this method is it's can obtain the accurate data of carbon emissions in the operating stage. But the operability is small and is greatly influenced by the environment. The last method is the most popular one and is the most frequent to use which is called carbon emission factor method. The total carbon emissions are summed up by multiplying the corresponding carbon emission factor by the amount of building materials used, the amount of energy consumed, the time of the equipment operated in the life cycle of the construction. The paper also uses carbon emission factor method to calculate the carbon emission of prefabricated construction and conventional construction in established boundary.

2.2 Carbon efficiency

In order to measure the relationship between carbon mission and actual activities of production, many researchers have put forward a series of concepts just like carbon emission intensity [5,6], carbon productivity [7], carbon benefits [8,9], the essence of all these concepts was to reflect the relationship between carbon emission and output of production. Among them, carbon intensity was defined as the carbon emissions per economic benefits produced. And the carbon intensity declined with the technological progress and economic growth. For carbon efficiency, there is no complete definition now. Currently, most of the researches relate carbon efficiency to the carbon emission in the production or associate carbon efficiency with production efficiency, considering the economic benefits of carbon emissions. For example, D. Z. Li [10] created a new concept of life-cycle carbon efficiency on the basis of estimating the life-cycle carbon emissions of the residential building which was defined as the ratio of its life-cycle value to carbon emission. Zheng [11] set up the model of carbon efficiency based on process carbon sources. The method of carbon efficiency were used to carry out measure of energy-conservation and emission-reduction effectively. Li [12] established carbon efficiency evaluation index system, and

focused on the carbon emission dynamics of machine operation process, three carbon efficiency indicators were defined for production rate, material removal and economic return rate.

From above literature review, it's evident that there are many studies on estimating carbon emissions of construction. In addition, most relevant studies calculate carbon emissions with an accurate calculation boundary of conventional construction while fewer researches focus on the carbon emission of the prefabricated construction. More importantly, to the best of authors' knowledge, very little has been done to study linkages between carbon emission and value creation of a construction. Therefore, the previous literature provides no effective solutions so as to balance the two important issues. This paper intends to fill in this knowledge gap through constructing a carbon efficiency model for prefabricated construction and conventional construction.

3 THE METHODOLOGY

In this paper, a carbon efficiency model is carried out on the basis of calculating carbon emission of prefabricated construction and conventional construction. From the perspective of benefit maximization, the essence of carbon efficiency is to achieve the goal of project completed with the lowest environmental output. Carbon efficiency not only embodies the theoretical essence of value engineering, but also reflects the construction efficiency from the view of environmental impact. This is the real low-carbon construction if the same construction project can be done with the shortest time, the lowest carbon emissions meanwhile can achieve the goal of good quality.

The main ideas of this paper are as follows: Firstly, finding out the research gap of the existing research meanwhile expounding the importance and necessity of carbon efficiency research based on analysing the present situation of construction industry and previous research results. Secondly, identifying the carbon emission calculation boundary, classifying all kinds of carbon sources and determining the calculation method through the analysis of construction characteristics of prefabricated construction and conventional cast in-situ construction in the construction stage. Thirdly, exclaiming the research significance and research method of carbon efficiency and establishing the carbon efficiency indicator on the basis of the calculation of carbon emissions. Finally, obtaining the carbon efficiency of prefabricated construction and conventional cast in-situ construction and providing the measurements to improve the carbon efficiency through the case study of two kinds of construction methods. Research steps are shown in figure 1.

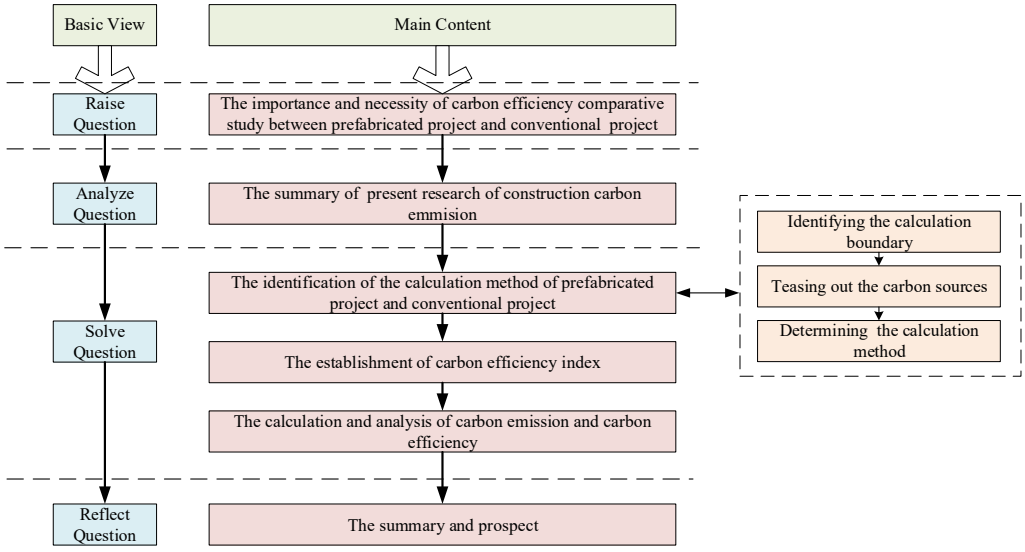

Figure 1. The research steps.

3.2 Calculation boundaries

Construction stage refers to all the production activities involved in the preparation of the project to the implementation, including the production and the transportation of the materials, on-site construction and other specific activities. Carbon emissions are consist of the usage of building materials and electricity and diesel consumed by the operating machines, including a series of process from site formation, foundation construction, main structure construction, equipment installation to the completion. Therefore, the research scope of this paper is carbon emissions generated by the building materials production, building materials transportation, the energy consumption of on-site machine and construction waste transportation. As a result of this paper researches two different construction methods which are prefabricated construction and conventional construction, the corresponding part of the construction activities are different. The main difference of these two kinds of construction methods is a large amount of prefabricated components are used in the prefabricated construction. Hence, the production and transportation of prefabricated components also generates the carbon emissions. So these two process are also incorporated into the carbon emission calculation boundaries. The scientific calculation boundaries are shown in figure 2.

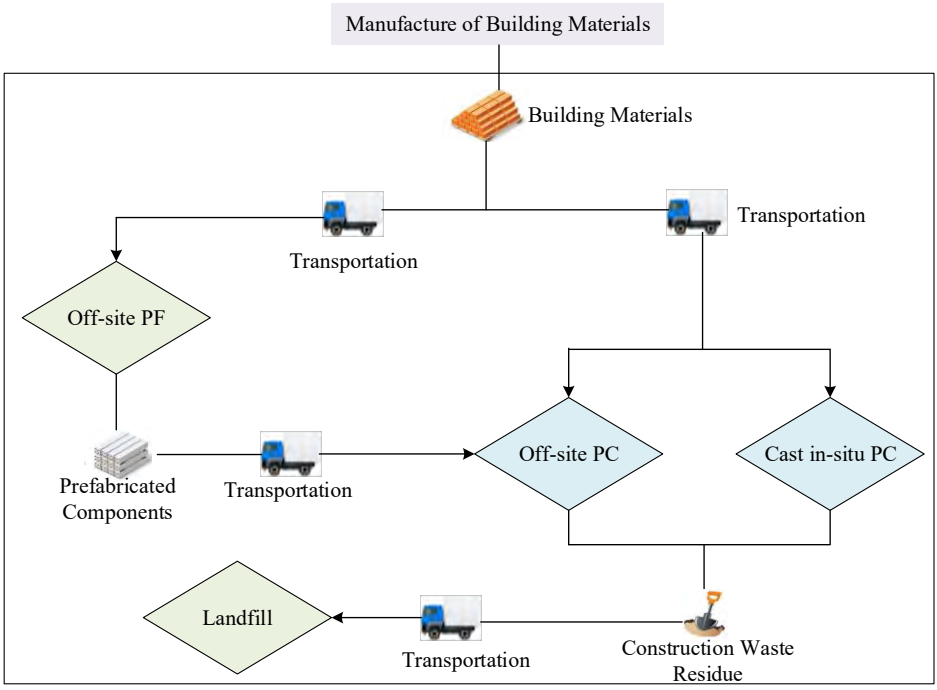

Figure 2. The calculation boundaries of two kinds of construction methods.

3.3 Classification of carbon sources

According to the figure 2, it can be easily found that there are three kinds of carbon sources: materials carbon emission, energy carbon emission and transportation carbon emission.

For energy carbon emission, it's almost the energy consumption of the machine used in the construction.

For materials carbon emission, it's generated by the main materials used in the construction, including cement, concrete, steel, sand, glass and lots of prefabricated components.

For transportation carbon emission, it includes transportation of material to on-site, transportation of materials to prefabricated factory, transportation of prefabricated components and the transportation of construction waste.

3.4 The calculation of carbon emissions of two kinds of construction methods

3.4.1 The calculation of energy carbon emissions of two kinds of construction methods

For both conventional construction and prefabricated construction, the energy consumption includes the electricity consumption and diesel consumption. According to the relevant literature [13,14], the energy carbon emission can be estimated as:

$$E_E = \sum_{i=1}^{n} C_{Ei} * F_{Ei} \quad (1)$$

Where E_E is the energy carbon emission, i is the type of construction energy, n is the total number of construction energy types, C_{Ei} is the amount of type i construction energy (L,m^3 or KWh), F_{Ei} is the carbon emission factor of type i construction energy.

3.4.2 The calculation of material carbon emissions of two kinds of construction methods

For both conventional construction and prefabricated construction, the main materials includes cement, concrete, steel, sand, glass. Besides, for the prefabricated construction, another main material is prefabricated components. According to the relevant literature [13,14], the material carbon emission can be estimated as:

$$E_M = \sum_{i=1}^{m} C_{Mi} * F_{Mi} \quad (2)$$

Where E_M is the energy carbon emission, i is the type of construction material, m is the total number of construction energy types, C_{Mi} is the amount of type i construction material (t), F_{Mi} is the carbon emission factor of type i construction material.

3.4.3 The calculation of transportation carbon emissions of two kinds of construction methods

For conventional construction, it includes two kinds of transportation: transportation of material to on-site and transportation of construction waste. For prefabricated construction, it includes four kinds of transportation: transportation of material to on-site, transportation of material to prefabricated factory, transportation of prefabricated components and transportation of construction waste. According to the relevant literature [13,14], the material carbon emission can be estimated as:

$$E_T = \sum_{i=1}^{j} C_{Ti} * F_{Ti} \quad (3)$$

Where E_T is the energy carbon emission, i is the type of transportation, j is the total number of transportation types, C_{Ti} is the distance of type i transportation (km), F_{Ti} is the carbon emission factor of type i transportation.

The total carbon emission can be estimated as:

$$E_{total} = E_E + E_M + E_T \quad (4)$$

Where E_{total} is the total carbon emissions.

3.5 The establishment of carbon efficiency

In general, the economic value of a construction project is generally reflected by the series of economic indicators of price or profit, while the price of house is easily affected and fluctuated by the factors such as the external environment, macroeconomic policies and currency levels. But it's easy to calculate and reflect the value of a construction project with price or profit. Of course, value can't only be reflected by the simple economic indicators, there also has a lot of application of the value of engineering theory. The value of a project can also be fully reflected by the ratio obtained by comparing the realized function with the cost of consumption. For most of the developers, they have also been exploring how to use the lowest cost to build the project which satisfies a string of requirement pertaining to quality and functionality. However, the theory of value engineering still represents the economic value of the project. It's impossible to judge only by the theory of the value engineering if carbon emissions are to be linked to economic values to determine the contribution of construction carbon emissions to the economic value of the project. Therefore, carbon efficiency is put forward to measure the economic benefits brought by the carbon emissions.

Tracing the source, the concept of eco-efficiency was first proposed in the World Commission on Sustainable Development (WCSBD) in 2000. And pointed out that "eco-efficiency can reduce the life-cycle environmental impact and resource consumption to meet the bearing capacity of the earth by providing competitive products and services to satisfying the human needs and improving human life" [15].

$$\text{eco} - \text{efficiency} = \frac{the\ value\ of\ products\ or\ services}{environmental\ impact} \quad (5)$$

The concept of carbon efficiency is derived from the development of eco-efficiency, which means the production target achieved when release a certain amount of carbon emission. The carbon efficiency defined in this paper refers to the construction area completed by releasing carbon emissions per construction period which is the reflection of the carbon efficiency based on the view of construction efficiency. When the construction area is certain, the shorter construction period, the faster construction

speed and the less carbon emission means the higher carbon efficiency. Obviously, the higher carbon efficiency means the higher economic value of construction.

According to the comparison of prefabricated construction and conventional construction, it's clear that the construction speed of prefabricated construction is faster than the construction speed of conventional construction. The faster speed of construction means the shorter period, so days of activity on-site is less, then resource consumption is reduced, finally the amount of carbon emissions are significantly reduced. Therefore, construction period is a key factor influencing carbon efficiency. Besides, the larger construction area, the more consumption of energy consumption and material usage which cause more carbon emissions. Therefore, construction area is a key factor influencing carbon efficiency. Through the analysis, there are three key factors influencing carbon efficiency, which are construction area, construction period and construction carbon emissions. And carbon efficiency can be estimated as:

$$CE = \frac{S}{T * E_{total}} \tag{6}$$

Where CE is the carbon efficiency ($m^2/(kg * d)$), S is the construction area (m^2), T is the construction period (d).

After this paper, the author has compare the carbon efficiency through the case study of two kinds of construction methods, and a result is found that the carbon efficiency of prefabricated construction is higher than the carbon efficiency of conventional construction.

4 CONCLUSION

This paper mainly analyses the economic benefits of carbon emissions from the prefabricated construction and conventional construction through the carbon efficiency indicator, which essentially reflect the construction efficiency of two kinds of construction methods. Firstly, the paper identifies the calculation boundaries of carbon emissions and clarifies three types of carbon sources in the construction stage, which are energy carbon emissions, material carbon emissions and transportation emissions. Then establishes the carbon efficiency indicators on the basis of calculation of carbon emission. Finally a result is found that the carbon efficiency of prefabricated construction is higher than the carbon efficiency of conventional construction through two actual case studies. However, the prefabricated construction in China is still in preliminary stage with the situation of low precast level and unrealized prefabricated standardization, there is still a big gap to the prefabricated construction of western countries. Therefore, the prefabricated construction needs to be improved and carbon efficiency can be improved. There are some measures are provided to improve the carbon efficiency of constructing. Enhancing the precast level, implementing prefabricated components standardized, optimizing site management is the main key to realize the low carbon construction.

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