

A systematic literature review of carbon emissions in the Chinese construction industry

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Abstract. In order to clarify the current situation of research on carbon emissions of China's construction industry and point out the research direction for the related research of carbon emissions in China and similar economies in the world, this study uses the systematic literature review method to screen the articles related to carbon emissions of China's construction industry from 2014 to 2021, and 134 papers were kept. These articles were analyzed from three aspects: carbon emission stages, research scope and research method. This study finds that: 1) in terms carbon emission stages, the amounts of articles on the whole life cycle of Chinese construction industry is the largest, accounting for 47.01%; The second is the articles on the materialization stage, accounting for 17.91%. 2) In terms of research scope, the research on individual projects and the research from the industry level accounted for 61.94% and 38.06% of the total amount of articles respectively. Among the articles on individual projects, the articles on buildings were the most, accounting for 67.47% of such articles. Among the articles on the industry level, the articles on carbon emissions of national construction industry were the most, accounting for 60.78% of such articles. 3) In terms of research method, the quantitative method used in micro-level research is mainly the carbon emission coefficient method, and the analysis method is mainly the life cycle assessment method; the quantitative method used in macro-level research is mainly the input-output method, and the analysis method is mainly decomposition analysis methods.

Keywords: Systematic literature review; Carbon emission; Construction industry; China.

1. Introduction

In recent decades, global warming has been one of the severe challenges to mankind, and the increase of carbon emissions is one of the main reasons for global warming¹. In the past 100 years, the concentration of carbon dioxide in the atmosphere has increased significantly and continues to increase at a rate of 2ppm/a². As a result of the associated greenhouse effect, the global temperature increased by 0.85°C on average from 1880 to 2012³. The construction industry is one of the three major sectors of energy consumption and is one of the main areas of responsibility for direct and indirect carbon emissions. According to the International Energy Agency (IEA), the building and construction sector was reported to be responsible for 36% of the world's energy consumption and approximately 40% of carbon emissions⁴. With the acceleration of urbanization and rapid economic growth, China has become the largest greenhouse gas emitter in the world⁵. The construction industry is particularly concerned in China. The carbon emissions of it accounted for 35-50% of China's total emissions, and its growth contributed 48.3% to China's emissions growth from 2001 to 2015⁶. Given the vast population, massive urbanization, and the ongoing modernization process, the ensuring excessive construction projects would make the emissions mitigation tasks even more challenging⁷.

There have been a lot of valuable studies on the carbon emissions of China's construction industry, but it needs to be reviewed to sort out the past and clarify the future direction. Before this, some scholars have published a review related to carbon emissions of China's construction industry. These reviews mainly focus on the assessment of carbon emissions^{8,9}. Some other reviews focus on low-carbon innovation research¹⁰. They cover a short time, the content of the review is not comprehensive, and there is no article to review from the perspective of the existing research objects, emission scales and research methods of China's construction industry carbon emissions. Therefore, this study was carried out.

2. Methodology

Systematic literature review (SLR) is a method to identify, evaluate and synthesize all available studies related to specific research issues, subject areas or phenomena of interest. In this study, SLR method is adopted to comprehensively identify, analyze and summarize the previous research related to carbon emissions of China's construction industry in a scientific, rigorous and repeatable process. Fig.1 shows the entire search and screening process and the detail number of articles picked out in each step.

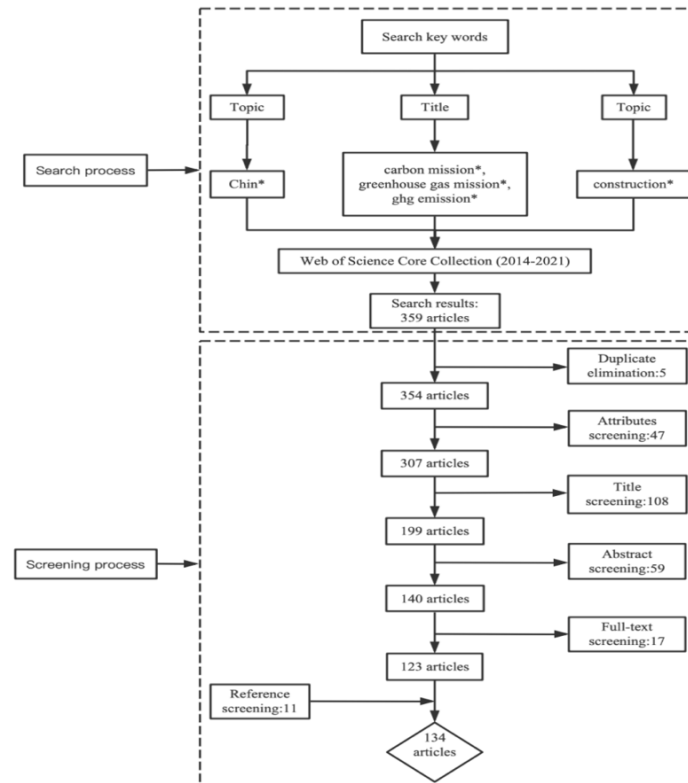


Fig. 1 Searching and screening process of the SLR

2.1 Search protocol

In order to obtain complete and accurate literature, it is necessary to select an appropriate electronic database and set search keywords. In this study, the Web of Science Core Collection (WOSCC) was selected as the literature source. This electronic database provides all high-quality articles indexed by SSCI, SCI and A & HCI.

According to the objective of this research, three sets of search keywords are determined. Among them, both ‘construction*’ and ‘Chin*’ are used as keywords in the Topic, covering titles, abstracts, author keywords and keywords plus. And ‘carbon mission*’, ‘greenhouse gas mission*’ and ‘ghg emission*’ are used as keywords in the Title, covering journal literature, conference proceedings papers, books or book chapters.

After the China-US Joint Announcement on Climate Change was issued in 2014, the Chinese government supported and paid more attention to the research related to the carbon emissions of China's construction industry, and academics conducted more research. Therefore, the time scope of the review was set at 2014-2021. Articles that do not meet these restrictions will not be adopted after search.

2.2 Screening protocol

The results obtained from the search process are not all focused on carbon missions in China's construction industry. Therefore, these irrelevant articles are deleted through the following 6 steps of the screening process:

(1) Duplicate elimination

The same article may be searched repeatedly by different keywords. For example, 'Urbanization impacts on greenhouse gas (GHG) emissions of water infrastructure in China: Trade-offs among sustainable development goals (SDGs)' can be searched by the keywords 'greenhouse gas emission*' and 'ghg emission*'. Therefore, a duplicate elimination is required to ensure that there are no duplicate copies in the results.

(2) Attributes screening

In this study, select Article in Document Types to refine. Since the research might not be mature or complete, Data Paper and Proceeding Paper are not considered. Review articles are also not considered because they usually summarize previous studies.

(3) Title screening

Title screening is required to filter these articles that are obviously not focused on carbon missions in China's construction industry. For example, the article 'the construction of Shenzhen's carbon emission trading scheme' meets the search requirements, but obviously, its research content is unrelated to the carbon emissions of China's construction industry.

(4) Abstract screening

In order to check whether detailed objectives and conclusions of articles are related to our SLR, the next step is to obtain the research information from the abstract. The articles that do not mention the carbon emissions of China's construction industry in the objectives and conclusions must be deleted.

(5) Full-text screening

In order to ensure the availability of articles that are eligible for the above screening steps, downloading and reading the full texts of the articles is a necessary step to pick up articles that cannot provide content related to carbon emissions in China's construction industry.

(6) Reference screening

The references of remaining articles and the review articles identified in step b attributes screening are good supplements to target any missing eligible articles. Therefore, in this step, all references are collected and screened again from the first step of the screening protocol.

2.3 Results of searching and screening

After the SLR analysis, 134 articles were kept. The detail results are given as follows:

In the search process, 359 articles were obtained from the WOBCC based on the keywords "construction*", "Chin*" and "carbon mission*" / "greenhouse gas mission*" / "ghg emission*". All articles were published in English between 2014 and 2021.

In the screening process, 5 articles were removed in the duplicate elimination process. 307 articles were obtained in the attribute screening process by choosing Article in Document Types to refine. 108 articles were eliminated in the title screening process. 59 articles were removed in the abstract screening process. 17 articles were removed from the list in the full-text screening process because they could not be obtained without permission or were not able to provide content related to carbon emissions of China's construction industry. 11 articles were added to the reference screening process.

3. Results

3.1 The stage of the carbon emissions

The articles that meet the requirements are divided into 12 types as shown in Table 1 according to the carbon emission stages targeted by their research. The largest amount is type A articles, with a total of 63 articles, accounting for 47.01% of the total amount of articles. Such articles have studied the five stages of carbon emissions in the whole life cycle of the construction industry, mainly focusing on the carbon emissions assessment of civil buildings and the related research on the carbon emissions of the construction industry in different countries and provinces in different periods. There are 24 articles of type B, accounting for 17.91% of the total number of articles. This kind of article

studies the carbon emissions in the material preparation and construction stage of China's construction industry, that is, the materialization stage (MAT). The research objects mainly include public buildings and civil buildings, prefabricated buildings and roads.

Articles of C, D and E types respectively study the carbon emissions of China's construction industry in the operation stage (including the use and maintenance of buildings), the construction stage, and the material preparation stage (including the production and transportation of materials). Among them, there are 10 articles of type C, accounting for 7.46% of the total number of articles; 9 articles of type D, accounting for 6.72%; There are 8 E-type articles, accounting for 5.97%. Both type C and type D focus on carbon emissions from civil buildings, public buildings, infrastructure and roads. There are 7 articles of type F, accounting for 5.22%. Compared with A-type articles, this kind of articles focus on the embodied carbon emissions, and do not consider the carbon emissions of the Chinese construction industry in the use of buildings, that is, do not consider the operational emissions. They also study the carbon emissions of other stages. The research objects of F-type articles include civil architecture, infrastructure and the construction industry of various provinces and cities in different periods.

The other six types of articles account for less than 5%. There are 5 articles of type G, focusing on the material preparation stage (including the production and transportation of materials), the construction stage and the operation stage (including the use and maintenance of buildings) of the construction industry. Four H-type articles have studied the carbon emissions in the waste disposal and recycling stages, which only account for 2.98% of the total amount. There is only one article in category I, J, K and L.

Table 1. The amounts of articles of each type.

Scope Type	Material preparation (Including production and transportation of materials)	Construction	Operation (Including use and maintenance of buildings)	Demolition	Waste disposal and recycling	Amount	Proportion
A	√	√	√	√	√	63	47.01%
B	√	√				24	17.91%
C			√			10	7.46%
D		√				9	6.72%
E	√					8	5.97%
F	√	√	√*	√	√	7	5.22%
G	√	√	√			5	3.73%
H					√	4	2.98%
I	√	√			√	1	0.75%
J	√				√	1	0.75%
K		√	√			1	0.75%
L				√	√	1	0.75%

Note: * The carbon emissions of buildings when they are used are not studied

3.2 The scope of research

The articles can be divided into two categories: Research on individual projects and research from the industry level. There are 83 and 51 studies in these two categories. Next, we will describe and analyze these two kinds of articles in detail.

(1) Individual project

According to the objects of case analysis in the studies, we divided 85 articles related to individual projects into 5 types: 1) buildings 2) roads 3) power stations 4) tunnels and 5) others. The amounts of articles corresponding to each type of article is shown in Fig 2.

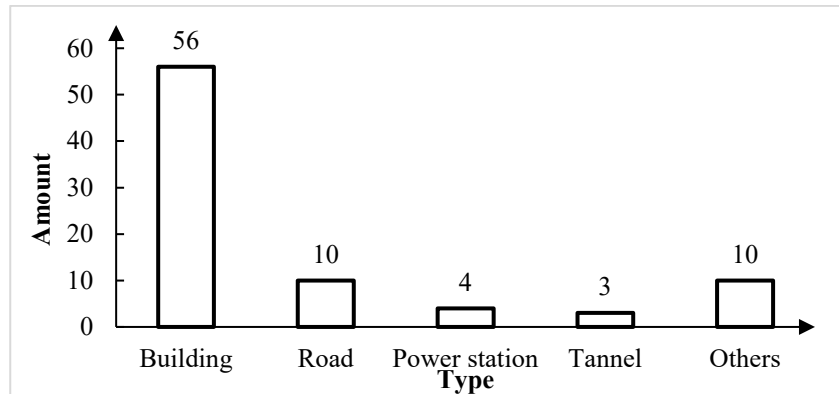


Fig. 2 The amounts of articles for each type.

The amounts of articles about buildings are the largest, with 56 articles, accounting for 67.47% of the total amounts of articles related to individual projects. Most of the articles focus on the carbon emissions at different stages of residential buildings and public buildings. In addition, some articles have carried out research on building materials and components. Some other articles have conducted relevant research on the carbon emission of prefabricated buildings from different perspectives. There are 10 such articles about roads, accounting for 12.05% of the total amounts of articles related to individual projects. Among these articles, 4 articles are related to asphalt pavement. Other articles have studied the carbon emissions of road construction and maintenance based on other different actual projects in China. Besides, there are 4 articles about power station, accounting for 4.82%. Three different power stations are studied in this kind of articles. There are 3 articles about tunnel, accounting for 3.61%. And 10 articles about other research objects accounting for 12.05%. Specific research objects are studied in such articles.

(2) Industry level

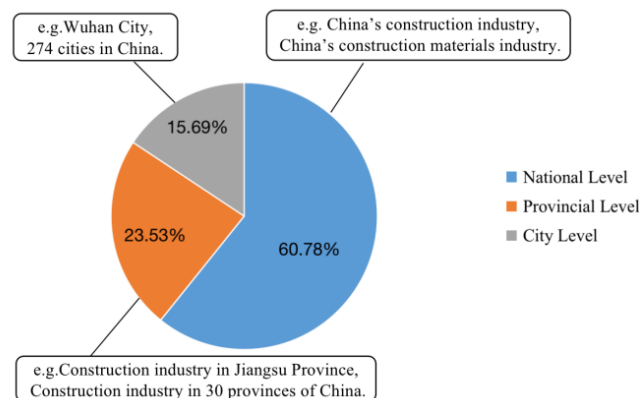


Fig. 3 The proportion of different types of papers

There are 51 articles studied from the industry level. According to different industry levels, we divide these articles into three levels: national level, provincial level and city level. The amounts of articles of these three levels are 31, 12 and 8 respectively, accounting for 60.78%, 23.53% and 15.69% of such articles respectively.

The national level articles all focus on the carbon emissions of China's construction industry in different time periods. Most of the provincial-level articles focus on the carbon emissions of the construction industry in many provinces of China in different time periods. Among the city-level articles, four articles have studied the construction carbon emissions of many cities in China in different time periods, and the remaining articles have studied the carbon emissions of the construction industry in Wuhan, Hong Kong and the carbon emissions of the construction materials industry in Mianyang and Shanghai.

3.3 Research methods

When studying the carbon emissions of China's construction industry, different research methods need to be used for different research purposes: the first type is the method of quantifying carbon emissions, the second type is the method of analyzing carbon emissions and other related issues, and the third type is the method of predicting carbon emissions. Research on the carbon emission of construction industry can be divided into micro-level research and macro-level research. However, when studying at the micro and macro levels, there are different choices for the same kind of methods. According to 134 articles, the main methods can be summarized as shown in Table 2.

Table 2. Research method

Category	Micro-Level (97)	Macro-Level (40)
Calculation (46)	On-site measuring method(2) Carbon emission coefficient method(30)	MFA(2) Input-output method(12)
Analysis (86)	Life Cycle Assessment (LCA)(46) Process-based method(7) Comparative analysis of multiple cases(4) Life Cycle Inventory (LCI)(3) Inventory-based method(1) Generic UM model(1)	Index Decomposition Analysis (IDA)(7) Structural Decomposition Analysis (SDA)(5) Data Envelopment Analysis (DEA)(4) STIRPAT(4) Tapio Decoupling Index(2) Sensitivity Analysis (SA)(1) Structural Production Layer Difference (SPLD)(1)
Prediction (5)	Uncertainty Analysis(1) Random forest-based predictive model(1) Quota-based GHG emissions quantification model(1)	System Dynamics (SD)(2)

Note: The numbers in parentheses represent the number of articles for the corresponding method.

(1) Calculation methods

For the micro level, most of them use the carbon emission coefficient method to quantify carbon emissions, but the sources of emission factors used are different. For example, some emission factors come from IPCC regulations, some from national, provincial and industrial authoritative regulations, and some from journals. Only a few articles have quantified carbon emissions using the on-site measuring method.

At the macro level, most of the articles quantify the carbon emissions of China's construction industry based on the input-output method, but their data sources are different, including the regional statistical yearbook, the Chinese input-output table, the Chinese Statistical Yearbook, the China Energy Statistical Yearbook, the China Construction Statistical Yearbook, and the world input-output database (WIOD).

(2) Analysis methods

At the micro level, most articles use life cycle assessment (LCA) to analyze carbon emissions and other related issues. However, different scholars choose different methods. Some choose process LCA, some choose streamlined LCA, some choose hybrid LCA, and some scholars combine LCA with other technologies such as MFA, BIM. Many other articles used process-based method, comparative analysis of multiple cases and life cycle inventory (LCI) for analysis.

At the macro level, the articles using index disposition analysis (IDA) are the most. Among them, six articles used the Logarithmic Mean Divisia Index (LMDI) method, and only one used the generalized dividing index method. There are also some articles that use structural decomposition analysis (SDA), Data Envelopment Analysis (DEA), STIRPAT (stochastic impacts by expression on population, influence, and Technology) model and Tapio decoupling index.

(3) Prediction methods

There are few studies on carbon emission prediction. At the micro level, an article carried out uncertainty analysis on carbon emission calculation of the construction industry; an article applied the method based on random forest-based predictive model to predict the carbon emissions in the

early design stage of buildings; an article proposed a Quota-based GHG emissions quantification model, which is able to estimate GHG emissions during the planning stage of subway projects.

At the macro level, an article introduced system dynamics (SD) to estimate the carbon emissions and intensity of China's construction industry. A carbon mission of construction industry (CECI) prediction model of Jiangsu Province was established in another research by using SD to accurately predict the provincial CECI peak.

4. Discussions

4.1 Discussions on the different stages

According to the results in 3.1, the amounts of articles on the whole life cycle of Chinese construction industry is the largest, with 63 articles, accounting for 47.01% of the total amounts of articles. Because this research involves the most emission stages, and the assessment of carbon emissions is the most comprehensive. According to the Research Report on building energy consumption in China (2020), the total carbon emissions of the whole construction process in China account for more than half of the total carbon emissions of the country, and the carbon emissions of the materialization stage (including material preparation and construction) account for 29%. Moreover, the duration of materialization stage is usually short, a large amount of CO₂ is produced in a short time, and the carbon emission intensity is great. So, the research on the materialization stage is of great significance to carbon emission reduction. Therefore, there are many related studies, accounting for 17.91%, and the research on the two stages of the materialization process: the material preparation stage and the construction stage also accounted for 5.97% and 6.72% respectively. While the carbon emissions in the operation stage (urban residential construction, public buildings, rural buildings) accounted for 22%, which was also a hot research topic. 7.46% of the articles studied this stage. The carbon emissions in the materialization stage and the operation stage are so huge, some articles (3.73%) also combine these two stages for research.

4.2 Discussions on the different scopes

According to the results in section 3.2, there are 56 articles on building carbon emissions. This is because buildings are the most common construction projects in the Chinese construction sector. According to the China Statistical Yearbook (2021), in 2020, China's housing construction area reached 14947.53 million m², and the completed area reached 3848.215 million m². Building construction has a large scale and great carbon reduction potential, so it has been studied most. According to China Statistical Yearbook (2021), the total mileage of China's roads will reach 5.198 million kilometers in 2020. With the continuous growth of the mileage and traffic volume of China's road system, this number will continue to increase. Therefore, in order to reduce carbon emissions, it is very important to build sustainable and low environmental impact roads. Many articles have studied the carbon emissions of road construction and maintenance. Since the first expressway was built in China in the 1990s, the total length of expressways in China has increased rapidly. By 2020, the total mileage of expressways will reach 161 thousand kilometers, and the expressways are mainly asphalt pavement, accounting for more than 90%¹¹. The manufacturing of asphalt pavement raw materials and pavement construction consume a lot of energy and emit a lot of greenhouse gases. So, the carbon emission of asphalt pavement has also become the focus of research.

4.3 Discussions on the different methods

Carbon emission calculation is the basis of carbon emission analysis. The calculation formulas provided by IPCC and China's Building carbon emission calculation standard (GB / t51366-2019) are based on carbon emission coefficient method, and both have detailed provisions on carbon emission coefficients. The quantification method is relatively mature, so the carbon emission factor method has been widely used in the research at the micro level, and only a few articles have used the on-site measuring method. China will compile input-output tables of various regions (including 31 provinces,

autonomous regions and 42 departments) every five years. At the macro level, the input-output method can be used to quantify the carbon emissions of China's construction industry to obtain relatively complete data. Therefore, many articles choose this method. The analysis is carried out after the quantification of building carbon emissions. The angles of analysis are different, and the contents of research are not the same, so there are many analysis methods. The micro-level research usually focuses on the analysis of carbon emissions at different stages of the life cycle of a single building, and most of them using the LCA; The macro-level research usually focuses on analyzing the driving factors behind industrial carbon emissions or the relationship between carbon emissions and other indicators, and most of them using the decomposition analysis method. It is less difficult to predict at the micro level, and there are more methods to choose. When forecasting at the macro level, the data source is single, and the related research adopts SD.

5. Conclusions

In this study, the SLR method was used to screen the articles related to carbon emissions of China's construction industry from 2014 to 2021, and 134 articles were kept. These articles were analyzed from carbon emission stages, research scope and research method. This study found that in terms of carbon emission stages, the amounts of articles on the whole life cycle of Chinese construction industry was the largest, accounting for 47.01%; The second is the articles on the materialization stage, accounting for 17.91%. In terms of research scope, the research on individual projects and the research from the industry level accounted for 61.94% and 38.06% of the total amount of articles respectively. Among the articles on individual projects, the articles on buildings were the most, accounting for 67.47% of such articles. Among the articles on the industry level, the articles on carbon emissions of national construction industry were the most, accounting for 60.78% of such articles. In terms of research method, the quantitative method used in micro-level research is mainly the carbon emission coefficient method, and the analysis method is mainly the LCA method; The quantitative method used in macro-level research is mainly the input-output method, and the analysis method is mainly decomposition analysis methods.

This study clarifies the relevant research status of carbon emissions in the Chinese construction industry and points out the research direction for the related research of carbon emissions in China and similar economies in the world.

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