Exploring the Development of Low Carbon Emission Reduction in the Construction Industry under the Background of "Dual Carbon"

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Abstract. Under the "dual-carbon" background, this paper explores the development of low-carbon emission reduction in the construction industry. Firstly, it analyses the current status of research at home and abroad, covering the calculation method of building carbon emissions and influencing factors, pointing out the need to create a unified database of carbon emission factors, strengthen the research and development and application of emission reduction technologies at the construction stage and deepen the identification and analysis of the main influencing factors. Then, we put forward countermeasures for the development of low-carbon emission reduction, such as the development of assembly building technology, the improvement of unified technical standards, and the control of prefabricated component quality; the promotion of green and low-carbon technologies, the development of new building materials, and the promotion of photovoltaic building integration; the calculation of carbon emissions from buildings, the clarification of the calculation scope, and the correct selection of carbon emission factors; and the analysis of the trend of the factors affecting the carbon emissions from buildings, and the identification method of the main driving factors and their contribution values. It also analyses the trend of influencing factors of building carbon emissions and proposes the identification methods of main driving factors and their contribution values. Finally, the conclusion emphasises the importance of low-carbon emission reduction in the construction industry and the future outlook, providing a reference for promoting the green and sustainable development of the construction industry.

Keywords: building carbon emissions, low carbon emission reduction measures, green sustainable development

1 Introduction

As China's carbon-peak and carbon-neutral strategies are being pushed deeper and deeper, the National Development and Reform Commission, in the main tasks of the National Carbon Peak Pilot Construction Programme, has explicitly proposed accelerating the low-carbon transformation of urban and rural construction. To promote

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green low-carbon urban and rural planning and design concepts, improve energy-saving standards for new buildings, and promote green low-carbon building materials and construction methods. Therefore, the low-carbon emission reduction action for the construction industry has become an important issue for China's "dual-carbon" goal.

2 Analysis of Domestic and International Research Status

In terms of low-carbon emission reduction actions, research on the calculation of carbon dioxide emissions from the construction industry and the factors affecting carbon emissions can provide a scientific basis and technical support for the realisation of the goal of "carbon peaking and carbon neutrality".

2.1 Methodology for Calculating Carbon Emissions from Buildings

Both domestic and foreign countries are committed to researching carbon emission measurement methods and standards. In terms of standard establishment, international experience includes the SAP for residential building energy efficiency labelling launched in the UK in 1993, which uses the SBEM model to calculate energy consumption-related carbon emissions, focusing on heating, air conditioning, and lighting; and the carbon emission standard for the whole life cycle of buildings formulated by ASHRAE in the US in cooperation with ICC. Domestically, the Standard for Calculating Carbon Emissions from Buildings GB/T 51366-2019 was released in 2019, defining the relevant concepts and clarifying the methodology for calculating and accumulating whole-life carbon emissions in phases. In addition, the General Specification for Building Energy Efficiency and Renewable Energy Utilization GB55015-2021 requires project reports to include analyses of energy consumption, renewable energy utilisation and carbon emissions. In Guangdong and Shandong, guidelines for calculating carbon emissions from buildings have been implemented on a trial basis, while in recent years, Heilongjiang and Hebei have issued standards for calculating carbon emissions from the whole building process and the operation phase, providing specific guidance and requirements for the green and low-carbon transformation of the urban and rural construction sector.

There are three main calculation methods: the measurement method, the material balance method, and the emission factor method. Among them, the actual measurement method relies on field experiments on existing projects or professional tool tests to directly obtain carbon emission data; the material balance method is based on the principle of mass conservation, and estimates carbon emissions by comparing the balance of inputs and outputs, and has the function of verifying the accuracy of the other calculation methods; and the emission factor method focuses on analysing the energy consumption of the various phases of the production process, and combining with the specific emission factors, the total amount of carbon emissions is calculated. The total amount of carbon emissions is calculated. This method is not only applicable to individual buildings but also can be widely applied to the carbon emission accounting of macro buildings, so it has been widely used in the construction industry.

2.2 Analysis of Factors Affecting Carbon Emissions from Buildings

Currently, the mainstream methods for identifying the factors affecting carbon emissions include the Log Mean Dichotomous Index (LMDI) method, the STIRPAT identification model, and the Structural Decomposition Analysis (SDA) method [1]. The LMDI model, rooted in the theory of Exponential Decomposition Analysis (IDA), is good at analysing the drivers of changes in the variables and their share of contribution and is characterised by its wide applicability, residual-free decomposition, easy operation, and intuitive interpretation of the results. The STIRPAT model, as a stochastic regression analysis tool, is an extension of the IPAT (Environmental Impacts = Population x Affluence x Technology) framework, which supports elasticity assessment of the factors and is flexible enough to handle single-factor or multi-factor integrated investigations. As for the SDA approach, the core of the approach is to refine the change in the target variable (e.g., total building carbon emissions) into a collection of contributions from multiple factors, and to quantify the changes in these factors to accurately assess their respective contributions to the change in the target variable.

Numerous scholars have proposed the influencing factors of construction carbon emissions through the above research methods: Li (2020) et al. through the exponential decomposition method, argued that it is necessary to comprehensively consider the relationship between economic growth, energy consumption and carbon emissions, to reduce the intensity of energy consumption, and to improve the labour productivity and technological level, to effectively control the growth of carbon emissions from the construction of buildings [2]. Zhao Hongyan (2022) et al. applied the STIRPAT model to analyse the carbon emissions from buildings in Jiangsu Province, and found that the contributing factors include the increase in urbanisation rate, population growth, the efficiency improvement of construction enterprises, the increase of steel production and the increase of transport distance, while the growth of GDP per capita and the expansion of tertiary industry become the key factors to inhibit the carbon emissions [3]. Cai Weiguang (2011) suggests that improving building energy efficiency can effectively curb the growth of building energy consumption [4].

2.3 Status and Problems

(1) The construction of a unified and comprehensive database of carbon emission factors is essential. Given that the accurate calculation of building carbon emissions is highly dependent on the accuracy of the carbon emission factors, the database needs to be continuously expanded and updated with the diversification of energy sources and dynamic changes in energy efficiency. In addition, although the Building Carbon Calculation Standard has provided a solution to the problem of missing carbon emission factor data, a more comprehensive and unified data standard system should be established in the future.

(2) Strengthen the research, development and application of emission reduction technologies at the building construction stage. Currently, the focus of carbon emissions in the life cycle of buildings is mostly on the operation phase, and emission reduction measures are also focused on reducing energy consumption in this phase. However, to achieve the goal of zero-carbon buildings, it is necessary to start from the source, conduct in-depth research and promote low-carbon technologies in the selection of building materials and the construction process, to realise a comprehensive reduction of carbon emissions in all phases of the whole life cycle of buildings.

(3) Deepen the identification and analysis of key factors affecting building carbon emissions. Existing research on building carbon emissions focuses on current emission levels and short-term emission reduction strategies, while in the future, long-term trends such as population growth and changes in energy consumption structure should be taken into account to comprehensively identify the key factors affecting building carbon emissions. On this basis, a long-term evaluation mechanism should be established to scientifically assess the long-term sustainability of emission reduction strategies and their positive impact on the environment.

3 Reflections on Countermeasures for The Development of Low-Carbon Emission Reduction

In light of the current situation of China's construction industry, to achieve the goal of "double carbon", it is necessary to strengthen carbon emission calculation standards, identify influencing factors and formulate countermeasures. Green construction technology should be upgraded from the design side, and zero-carbon building standards should be pursued. Combined with national policies, we will focus on assembly building, green and low-carbon technologies, whole life cycle carbon emission calculation and analysis of influencing factors, to promote the transformation and high-quality development of the construction industry.

3.1 Assembly Building Technology

Assembly building technology is representative of modern industrialised production methods, at present, the construction enterprises have created a relatively complete technical system and industrial chain in prefabricated assembled concrete structures, steel structures, modern wood structures, etc. It has significant advantages in energy saving and environmental protection, shortening the construction period, construction progress organisation, improving accuracy and construction efficiency, controlling construction quality, etc. It is an important way and hand for the construction industry to develop green building and intelligent construction modes, at the same time, the development of assembly building technology also needs to pay attention to the following issues.

(1) Establish and improve unified technical standards. Accelerate the development of a national system of technical standards for assembled buildings, clarify the standards for design, production, construction, acceptance and other aspects, and ensure that

cross-regional projects follow uniform norms. Strengthen research on design standards, provide detailed guidelines and case studies, and provide guidance on the reasonable splitting of components and node design to ensure structural safety and reliable performance.

(2) Control the quality of prefabricated components in the manufacturing process. Strengthen supervision, and establish a strict quality control system to ensure that the quality of components meets the standards. Encourage enterprises to adopt advanced technology and equipment to improve production efficiency and quality stability.

(3) Production capacity to match demand. Increase support for prefabricated component production enterprises and encourage them to expand their production scale and increase their production capacity. At the same time, rationally plan the layout of prefabricated component production bases to ensure that the supply of prefabricated components can meet the needs of assembly building projects.

(4) Improve the level of construction technology. Strengthen training and technical guidance for construction enterprises, and improve the technical level and operational ability of construction personnel. At the same time, encourages construction enterprises to carry out technological innovation and explore new techniques and methods suitable for assembly building construction.

(5) Reduce construction costs. The construction cost of assembled buildings is high, and the main reasons include the production cost of prefabricated components, transport cost, installation cost and so on. The production cost of prefabricated components can be reduced through technological innovation and large-scale production; optimise transport solutions to reduce transport costs; improve construction efficiency and reduce installation costs. At the same time, policy guidance should be strengthened to help reduce the total cost.

(6) Control of Post-Maintenance Costs. Due to its unique structure and connection method, the assembly building may encounter new maintenance challenges such as cracks in prefabricated parts and loose nodes during the operation phase, which will lead to an increase in the uncertainty of maintenance costs in the later stage. It is necessary to deepen the research and management of post-assembly building maintenance and build a comprehensive maintenance system and technical specifications. In addition, in the project planning, design and construction phases, post-maintenance considerations should be incorporated in a forward-looking manner to enhance the durability and maintainability of the building, to effectively control the long-term maintenance costs.

3.2 Green and Low-Carbon Technologies

Green buildings should strengthen low-carbon technologies in the whole life cycle of the building (including the production of building materials, building construction, operation and other links), to significantly reduce carbon emissions over the whole life cycle, to reduce energy consumption and carbon emissions and achieve sustainable development in the field of construction. Specifically, the development of green low-carbon technologies can be promoted from the following perspectives.

(1) Developing new green and low-carbon building materials. For example, the use of high-performance concrete materials, such as hammam concrete, can be used to replace limestone raw materials with fibres and other green materials, reducing the cement clinker factor; high-ductility concrete and ultra-high-performance concrete can be added to improve the hardness and durability of concrete through the addition of different new types of materials, thereby reducing the use of cement and lowering carbon dioxide emissions. In addition, the development of new low-carbon cement varieties and the application of low-carbon cementitious materials are also included.

(2) Promoting photovoltaic building integration. Designing, constructing and installing photovoltaic power generation systems at the same time as buildings, so that they have the function of both power generation and building components and materials, photovoltaic building integration can make effective use of solar energy, reduce dependence on traditional energy sources and reduce carbon emissions.

(3) Energy-saving management of buildings. Establishing an energy-saving regulatory system for public buildings, scientifically formulating benchmarks for energy-consumption limits; regularly carrying out commissioning and maintenance of key energy-using equipment in public buildings; promoting the construction of digital intelligent operation and management platforms for buildings, and promoting the application of high-efficiency, flexible and intelligent regulation and control technologies, to realise the overall participation of building complexes in electric power demand response and peak shifting.

(4) Upgrading the energy efficiency of existing buildings. Organise and implement energy-efficiency diagnostics, carry out comprehensive mapping surveys of existing buildings in towns and cities, set up relevant databases and project reserves, and determine the key elements of retrofitting in the light of the safety of housing.

(5) Strictly managing the demolition of buildings. Promote organic renewal of cities, adhere to the "retention, change and demolition" approach, strengthen the repair and transformation of old buildings and retain their use, and eliminate the waste of energy and resources caused by large-scale demolition and construction.

3.3 Calculation of Carbon Emissions from Buildings

The calculation, quantification and monitoring of building carbon emissions data are the basic means for the government to accurately monitor and manage the process of carbon peaking and carbon neutrality targets, and they are also important indicators for enterprises to explore the space for carbon reduction. Compared with the United States and other developed countries, China's building operation stage carbon emissions accounted for a low proportion, and building materials and construction carbon emissions accounted for a high proportion, which is mainly due to the large volume of new buildings, China's annual new construction is about 7%, developed countries about 1% [5]. However, the calculation scope of carbon emissions should be based on the boundary of the whole life cycle of the building, including the production stage of building materials, the construction stage, the operation stage, and the demolition stage. Among them, the operation phase usually has the largest carbon emissions, accounting for 60-80 per cent of the carbon emissions of the whole life cycle of a building. This phase has a long period and often takes the design year as the time boundary for calculation. Carbon emissions in this phase mainly come from the energy consumption of heating, cooling, lighting and ventilation of the building. As people's demand for indoor comfort improves, energy consumption continues to increase, resulting in high carbon emissions, so the operation phase has become the focus of attention in the calculation of carbon emissions from buildings.

In the choice of the calculation method, applying the emission factor method to measure each building stage and then summarising them in a single building can accurately obtain the carbon emissions. The measurement of carbon emissions from buildings should be carried out in six steps: defining the scope and area of the building, defining the carbon emission unit process of the building, collecting the activity level data of the carbon emission unit process, collecting the carbon emission factor of the carbon emission unit process, calculating the carbon emissions of the building, and releasing the results of the measurement to the public. Carbon emissions in the life cycle of a building should be the sum of carbon emissions from each unit process in the material production phase, construction phase, operation and maintenance phase, and dismantling phase. There are several points to note.

(1) Define the scope of calculation. For different project types, determine the scope of calculation accordingly. For example, the calculation of carbon emissions from existing buildings may only focus on the carbon emissions during the operation and use phase, while for new buildings, it is necessary to consider the entire life cycle from the production of building materials to demolition and recycling. The Standard for Calculating Carbon Emissions from Buildings (GB/T 51366-2019) focuses on the carbon emissions generated during the operation, construction and demolition phases, and the production and transport of building materials in the life cycle of a building, and gives the corresponding calculation formulas and methods. When considering the carbon emission scenarios in the whole life cycle of a building, it is also necessary to include in the calculation the waste disposal to landfill in the demolition phase of the building, the contribution of recycling of building materials, and the carbon sink of the greening environment. Reference can be made to the calculation method in the Building Carbon Emission Measurement Standard (CECS 347:2014):

$$E_{LC} = E_{\mathrm{SC}} + E_{SG} + E_{YXNH} + E_{CJ} - E_{HS} - E_{TH} \quad (1)$$

Herein, E_{LC} - building whole life cycle carbon emissions (tCO2);

E_{SC} - Carbon emissions from buildings at the material production stage (tCO2);

E_{SG} - Carbon emissions from buildings during the construction phase (tCO2);

E_{YXNH} - Carbon emissions from buildings during the operation and maintenance phase (tCO2);

E_{CJ} - Building carbon emissions during the dismantling phase (tCO2);

E_{HS} - Building carbon emissions in the recycling phase (tCO2);

E_{TH} - Building Carbon Sinks (tCO2).

Building Carbon Emissions = ∑ Categorised Energy Consumption x Carbon Emission Factor

The emissions from each carbon unit process shall be the product of the activity level data of the carbon unit process and the carbon emission factor.

(2) Correctly select the carbon emission factor. The carbon emission factor, as an important indicator for measuring energy consumption in the life cycle of a building, must be based on building energy efficiency standards so that it can be effectively linked to energy efficiency labelling, green building certification and other efforts. When establishing a carbon emission factor database, the accuracy and timeliness of information sources should be considered. Generally, the following sources can be considered: (i) official published literature continuously issued by authoritative institutions; (ii) research reports of accredited academic institutions; (iii) various statistical yearbooks and reports; (iv) relevant basic data manuals; (v) process information within the factory; and (vi) industry standards and norms.

(3) Accurately collect activity data. It is difficult to capture the real carbon footprint of a building according to the facts, but it is possible to collect the activity level data reflecting the characteristics of energy, resource and material consumption in the unit process and the corresponding carbon emission factors according to the specific carbon emission unit process, and the carbon footprint of each stage of the life cycle of the building can be obtained. The information collected is as follows: (i) material production stage: the types and quantities of materials, components, parts and equipment used in the main structure, envelope and infill of the building; (ii) construction stage: the energy consumed in the transport of materials, components, parts and equipment, the energy consumed in the operation of construction machinery, the water consumed, and the energy consumed in the construction site office; (iii) operation and maintenance stage: the energy consumed in the operation of the building, the water consumed, the types and use of renewable energy, and the maintenance and maintenance of the building. (iv) Operation and maintenance stage: energy consumption and water consumption for building operation, type and amount of renewable energy, material consumption for maintenance and replacement activities, energy consumption for maintenance and replacement activities; (v) Dismantling stage: energy consumption for the operation of dismantling equipment, energy consumption for transport of dismantling waste; (vi) Recycling stage: type and amount of building materials, components, parts, and equipment recycled from the main structure of the building, the envelope, and the infill body.

3.4 Factors Affecting Carbon Emissions from Buildings

Comprehensively, the research views of many scholars indicate that the key influencing factors focus on indicators related to economic and social development and factors of energy consumption in building operations. It is generally agreed that carbon emissions from the construction industry are closely related to four factors: population and urbanisation rate, building area, building energy intensity and building energy structure. The contribution to carbon emissions from buildings should be analysed in light of the development trends and interaction mechanisms of each factor.

(1) Population and urbanisation rate. According to the seventh population census, China's population will grow slowly until 2030 and then gradually decline, with a total

population of about 1.275 billion in 2060; according to the law of linear growth of urbanisation, it is expected that China's urbanisation rate will reach the level of that of developed countries in the future, at about 75 per cent to 80 per cent. Household size has decreased from 3.1 persons in the sixth census to 2.62 persons in the seventh census, and the "Matthew effect" in population distribution is becoming stronger and stronger [6].

(2) Floor space. For the judgement of the future scale of floor area, the results of various research institutions differ greatly, but the overall consensus is that China's floor area in general will maintain a growth trend over a long period in the future (2030-2035). Building area according to the different scales of construction, as of 2060 there may be 85 billion, 80 billion, and 75 billion square metres of three kinds of stock size.

(3) Building energy intensity. The energy intensity of urban residential buildings will increase mainly due to the growth of energy demand for domestic hot water, air-conditioning and home appliances. For public buildings, from 2001 to 2020, the energy intensity of China's public buildings rose from 17.2kgce/m^2 to 24.7kgce/m^2, showing a year-on-year upward trend [7]. With the continuous improvement of building energy-saving standards, there will be a certain downward trend in the future in heating, cooling, lighting lifts, heating hot water, etc., and it is expected to be balanced under comprehensive development.

The energy intensity of rural commodities has doubled in 2020 compared to 2001, mainly due to a decline in the proportion of total energy consumption from biomass. Rural commodity energy use will also grow rapidly, with the completion of the battle against poverty in 2020 after the building of a moderately affluent society in all respects, the standard of living in rural areas will gradually improve, bringing about a change in the way energy is used, and the traditional use of energy: straw and rice straw, will increasingly shift to commodity energy use.

(4) Building energy structure. China's energy structure is dominated by electricity, gas, coal and liquefied petroleum gas; coal is mainly concentrated in rural areas and centralised heating in the north; gas is mainly concentrated in urban cooking, domestic hot water and the equipment of public buildings. Around carbon neutrality, the structure of building energy use will also change, mainly in the electrification of cooking, heating, and domestic hot water. Energy transition is also a long-term task for the building sector, which requires multi-sectoral linkages, especially with the energy sector.

Using the LMDI decomposition method, the interaction of factors affecting building carbon emissions can be studied in depth, and the main drivers of building carbon emissions and the degree of influence can be explored by investigating their intrinsic mechanism of action [8].

The LMDI decomposition method can be used to analyse building carbon emissions using both multiplicative and additive modes of decomposition.

Multiplication mode with the formula:

$$\mathrm{C}=\sum_{S} C_S=\sum_{S}\left(P\frac{F}{P}\frac{E}{F}\frac{C}{E}\right)=\mathrm{Pgek} \tag{2}$$

Herein, S is the type of building, there are townhouses, rural houses, and public buildings; is the carbon emissions of different types of buildings, 10,000t; P is the total population, 10,000; F is the building area, 10,000m2; E is the energy consumption, 10,000tce; g is the per capita building area, m2; e is the building energy intensity, kg/m2; k is the total carbon emission factor, t-C/kgce.

The additive model has the formula:

$$\Delta C = C^T - C^O = (P^T g^T e^T k^T) - (P^0 g^0 e^0 k^0) = \Delta P + \Delta g + \Delta e + \Delta k \quad (3)$$

Herein, we set the time range of the study as [0, T]. The left side of the equation equals the amount of change in carbon emissions in the building sector, and the right side indicates the impact of various drivers.

According to the definition of exponential decomposition, the derivative of the target variable concerning time T is taken to obtain an expression for the contribution of each decomposition factor:

$$\Delta C_x = \sum \frac{C^T - C^0}{\ln C^T - \ln C^0} \ln\left(\frac{X^T}{X^0}\right) \quad (4)$$

Herein, x is the different drivers P, g, e, k.

According to the contribution value of each factor, multiple scenarios can also be set up to quantitatively analyse building carbon emissions at different times and under different energy-saving standards and policies by setting up a low-carbon scenario, an enhanced low-carbon scenario, a peaking scenario, an enhanced peaking scenario, and a neutralisation scenario, with the technical routes shown in Figure 1:

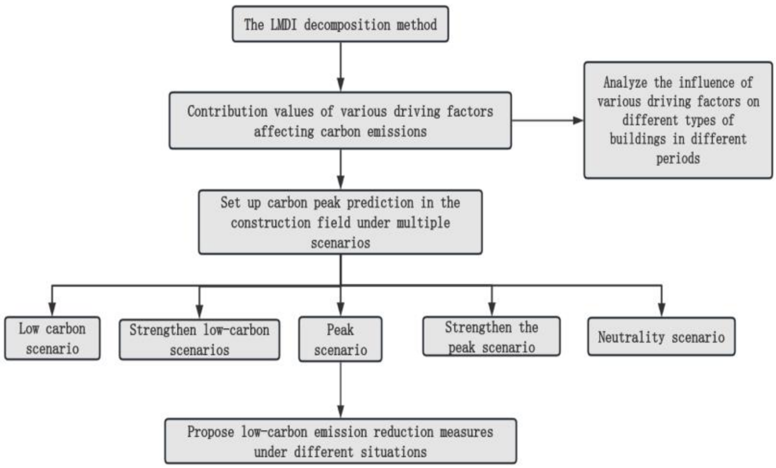

Fig. 1. Quantitative carbon emission analysis across scenarios from low-carbon to neutralisation pathways

4 Conclusion

Under the grand blueprint of the "double carbon" goal, the construction industry, as an important field of carbon emissions, its low-carbon emission reduction development is not only a key initiative to respond to the challenges of global climate change, but also a necessary way to promote China's economic transformation and upgrading, and to achieve high-quality development. Through the discussion in this paper, we deeply recognise the challenges and opportunities facing the construction industry in terms of low-carbon emission reduction.

Looking to the future, the construction industry must unswervingly take the path of green and low-carbon development, led by technological innovation, and continuously optimise the management of carbon emissions throughout the life cycle of buildings. From the production of building materials, and construction to operation and maintenance, every step of the process needs to incorporate the concept of green and low-carbon, and through the application of advanced technologies such as assembled buildings, green building materials, intelligent operation and maintenance, to achieve a significant reduction in building energy consumption and effective control of carbon emissions. We firmly believe that with the joint efforts of all parties, the construction industry will usher in a greener, low-carbon and sustainable future, and contribute China's wisdom and strength to global climate governance and sustainable development.

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