Carbon Emission Control in Civil Engineering Management: Optimization and Future Trends Based on Whole Life Cycle Management

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Abstract. Carbon mission control in civil engineering management is crucial for climate change response. Based on life-cycle management, optimizing carbon emissions has become a key topic and future trend. This paper analyzes carbon emissions in material production, supply, and construction stages, predicts energy-related emissions using ARIMA models, and proposes LCM strategies. By examining building material selection, construction processes, and emission sources, targeted optimization measures are proposed. BIM and LCA technologies are innovatively applied to enhance carbon data accuracy and managerial control. As global climate policies evolve and technology innovates, professional training in low-carbon management is essential. The widespread application of intelligent technology and low-carbon materials in civil engineering management holds significant promise.

Keywords: Civil engineering management, carbon emission control, ARIMA model, life cycle management, BIM technology

1 Introduction

Under the background of global climate change, civil engineering is an important field with high energy consumption and greenhouse gas emission, and its carbon emission control is particularly important. Civil engineering involves extensive infrastructure construction with far-reaching impacts, so it is critical to implement a full lifecycle management (LCM) strategy to optimize carbon emission control.

The China government attaches great importance to addressing climate change and promoting green and low-carbon development. It has promulgated laws and regulations such as the Environmental Protection Law and the Energy Conservation Law, and established a carbon emission trading system, which has been incorporated into corporate credit evaluation to enhance environmental awareness[1]. In terms of technological innovation, the combination of Building Information Modeling (BIM) and Life Cycle Assessment (LCA) improves the accuracy and timeliness of carbon emissions data to support decision-making. At the same time, the application of smart

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technologies and low-carbon materials is also advancing to achieve real-time monitoring and regulation of energy consumption and carbon emissions.

However, the domestic civil engineering field still faces the challenge of emission reduction awareness and lack of technical talents. In contrast, foreign countries started earlier in carbon emission control, with strict regulations and more advanced technologies, such as carbon emission prediction models based on big data and AI and research and development of low-carbon materials.

In the future, carbon emission management in civil engineering will be a key issue. Strengthening personnel training, promoting the application of smart technologies and low-carbon materials, and deepening international cooperation are the keys to achieving low-carbon development. Innovating engineering management concepts and practices and improving carbon emission control efficiency will help to cope with climate change, promote sustainable development, and realize the national low-carbon strategy and green transformation of the construction industry.

2 CO_2 is the Main Source of Carbon Emissions from Civil Engineering

The entire life cycle of CO2 projects in civil engineering, a major carbon emitter, spans from planning to scrapping, including material production, supply, construction, operation, maintenance, waste treatment, and recycling. High carbon emissions mainly occur during material production & supply (from building material manufacturing and transportation) and construction (from machinery, temporary facilities, concrete mixing, material processing, and worker transportation). This paper focuses on these two phases due to their significant carbon management needs.

In order to further understand the carbon emission sources in the production and supply stages of materials, the carbon emission factors of the following 22 building materials were obtained, as shown in Table 1:

Table 1. Carbon emission production factors of building materials [2]

serial number	Type of building materials	unit	Production factor (1CO2e/unit)
1	rebar	t	2.34
2	concrete	m^3	0.295
3	cement mortar	m^3	0.73
4	fired shale porous brick masonry	m^3	0.25
5	Aluminum alloy ordinary hollow glass window	t	0.386
6	ordinary flat glass	t	1.13
7	the Autoclaved Aerated Concrete board	t	0.126
8	fine aggregate concrete	m^3	0.295
9	lime mortar	m^3	0.73
10	waterproof roll	t	0.951

Carbon emissions can be calculated by the amount used according to the carbon emission factors of different building materials.

Table 2. Carbon emission factors of passenger and freight transportation modes in China[3]

Mode	Rail		Road		Water		Aviation	
	Factor	Rate	Factor	Rate	Factor	Rate	Factor	Rate
Freight ($kgCO_2$/t·km)	0.08	1	0.092	11.5	0.008	1	1.027	128.4
Passenger ($kgCO_2$/passeng er·km)	0.027	3.4	0.021	2.6	0.008	1	0.077	9.6

Carbon emission factors of passenger and freight transportation modes in China[2]

As can be seen from the table, different building materials in the process of production and transportation of carbon emissions there are significant differences. Therefore, there is a great

Potential for emission reduction lies in material selection and transportation optimization. Construction equipment's energy consumption and carbon emissions are also significant. This paper calculates these for main equipment, as shown in Table 2.

Table 3. Energy consumption, power and carbon emission of main construction equipment

Machinery	Power (kW)	Fuel Consumption (L/hour)	CO_2 Emissions (kg CO_2/hour)
Rotary Drilling Rig	300	30	80.4
Vibratory Pile Driver	250	25	67
Concrete Mixing Plant	250	25	67
Paver	220	22	58.96
Excavator	200	20	53.6
Bulldozer	180	18	48.24

The energy consumption and carbon emission of these construction equipment in the construction process are relatively large, so optimizing the use and management of construction equipment is of great significance to reduce carbon emissions. In addition to the above construction equipment, energy use during construction is also an important source of carbon emissions.

ARIMA, a statistical model for time series analysis, combines AR, I, and MA. It suits data with trends or periodicity. This paper uses carbon emission and energy use stats from construction (Table 3) and predicts China's construction industry's carbon trend from 2022-2025 (Fig 1) based on the 2014-2021[4] inventory (Fig 2) using the ARIMA model.

Emission_Inventory	2021	2020	2019	2018	2017	2016	2015	2014	unit
Raw_Coal	6.713287975	9.815029231	9.808782018	9.999815216	11.59745774	12.91479768	13.99523673	14.57836475	Mt CO2
Other_Washed_Coal	0.436575779	0.506292344	0.522511128	0.50834995	0.331395753	0.23856137	0.226094692	0.242434512	Mt CO2
Briquettes	0	0	0	0	0	0	0	0	Mt CO2
Coke	0.058970075	0.102694229	0.279029137	0.306069074	0.361587242	0.202799527	0.192156148	0.278741478	Mt CO2
Coke_Oven_Gas	0	0	0	0	0	0	0	0	Mt CO2
Other_Gas	0	0	0	0	0	0	0	0	Mt CO2
Other_Coking_Products	0	0	0	0	0	0	0	0	Mt CO2
Crude_Oil	0	0	0	0	0	0	0	0	Mt CO2
Gasoline	16.48343343	14.87928395	14.63051054	14.77977459	13.23825747	12.79748953	11.9578061	9.688407258	Mt CO2
Kerosene	0.30290737	0.328099066	0.486533582	0.524169367	0.295926539	0.303514399	0.379392999	0.316262004	Mt CO2
Diesel_Oil	16.30752215	15.5903748	16.40559622	16.81088656	18.44102002	17.36437086	17.19266388	17.07633627	Mt CO2
Fuel_Oil	1.271763924	1.29109068	1.008793307	1.008476475	1.369981866	1.644675269	1.6953684	1.413071027	Mt CO2
LPG	0.431745704	0.355039614	0.345333946	0.53193325	0.496241436	0.46242814	0.47275998	0.525358442	Mt CO2
Refinery_Gas	0	0	0	0	0	0	0	0	Mt CO2
her_Petroleum_Produc	0	0	0	0	0	0	0	0	Mt CO2
Natural_Gas	0.693594007	0.570432455	0.607164848	0.53802152	0.388931219	0.421342154	0.466717463	0.406217051	Mt CO2
Scope_2_Heat	0	0	0	0	0	0	0	0	Mt CO2
Scope_2_Electricity	0	0	0	0	0	0	0	0	Mt CO2
Other_Energy	0	0	0	0	0	0	0	0	Mt CO2
Process	0	0	0	0	0	0	0	0	Mt CO2
Scope_1_Total	42.69980041	43.43833637	44.09425473	45.007496	46.52079928	46.34997893	46.74577573	44.66625772	Mt CO2

Fig. 1. Energy Carbon Emission Inventory of China Construction Industry 2014-2021

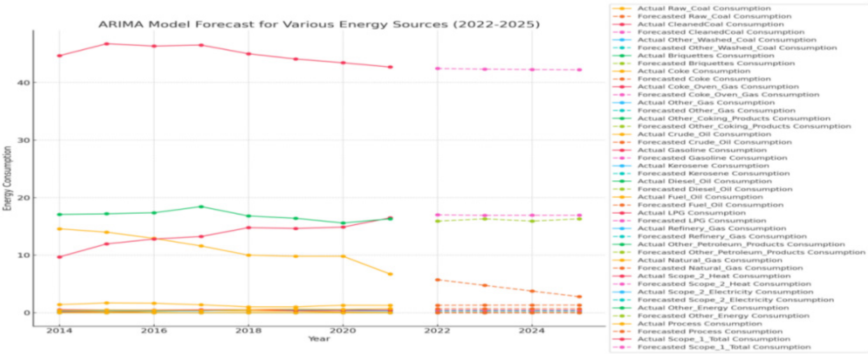

Fig. 2. Prediction of Energy Carbon Emission Model of Construction Industry from 2022-2025

Overall, most traditional fossil fuels such as raw coal and diesel show a downward trend, while some clean energy and alternative energy sources such as natural gas and liquefied petroleum gas are likely to remain relatively stable in the next few years. This projection is consistent with a global push for domestic carbon emissions and environmental policies, leading to a gradual cut-off in demand for traditional energy sources and an increase in demand for cleaner fuels.

3 Carbon Emission Optimization Strategy for Life Cycle Management

3.1 Multi-link Collaborative Optimization

Civil engineering's life cycle carbon management includes planning, material selection, construction, operation, and demolition. Initial phase focuses on green concepts, low-carbon materials, and energy simulations. Material selection involves eco-friendly options and LCA. Construction uses efficient equipment and recycling. Operation enforces energy management and education. Demolition uses eco-friendly techniques. Optimizing these stages reduces emissions and fosters sustainability.

3.2 Multi-Technical Support and Co-Construction

Life-cycle carbon emissions management requires technologies such as BIM, LCA, IoT and Big Data[5]. BIM technology digitalizes and integrates building information and supports carbon emission simulation, prediction and optimization decision-making. LCA assesses carbon emissions throughout the life cycle of buildings, identifies emission hotspots, compares different options, and selects the best. IoT and big data technologies monitor building energy consumption in real time, warn of abnormalities, analyze carbon emission trends, and provide energy efficiency optimization recommendations, See Figure 3 for details. Together, these technologies improve the efficiency and accuracy of carbon emission management, support carbon emission optimization at all stages from planning to demolition and recycling, and promote green and low-carbon development in civil engineering to achieve sustainable development goals.

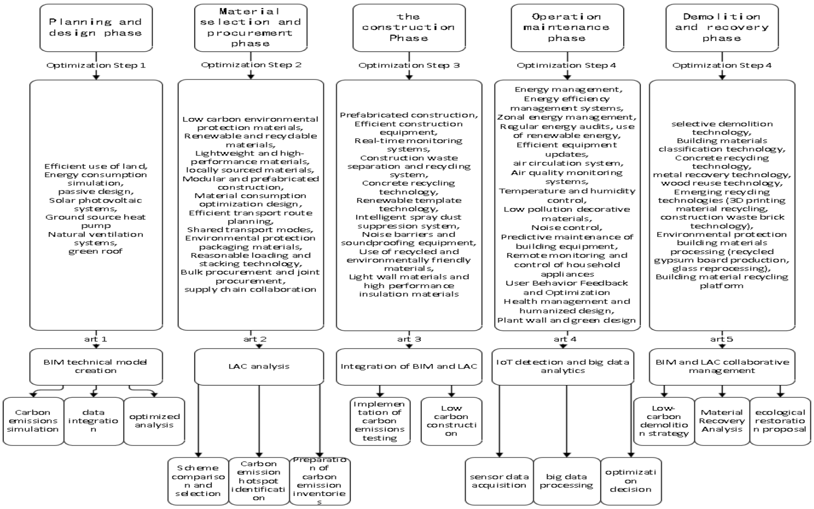

Fig. 3. Roadmap of carbon emission optimization strategy for life cycle management

3.3 Example Analysis

Shenzhen International Low Carbon City is located in the geometric center of the east bank of Dawan District, which is the only key area named after low carbon in Shenzhen[6]. Shenzhen International Low Carbon City achieves full life cycle carbon emission control through a number of innovative technologies. Efficient insulation and energy-efficient windows were used in the design phase to optimize natural light and ventilation. The construction phase uses low-carbon technologies and electric construction equipment and recycles construction waste. The operation phase is equipped with intelligent energy management system, utilizing renewable energy such as solar energy and wind energy, and adopting underground water source heat pump and centralized cooling system to improve energy efficiency. Rainwater recycling systems are used for greening and non-potable water needs.

4 Future Trends and Technology Outlook

(1) Deep integration and wide application of digital and intelligent construction

Deep integration and wide application of digital and intelligent construction Digital and intelligent construction will play a central role in carbon emission management, BIM, big data, AI and IoT technologies will promote real-time monitoring of construction equipment, optimize scheduling, and reduce energy consumption and carbon emissions. Intelligent equipment improves efficiency, reduces waste of resources, and promotes carbon emission management upgrade. In the future, with the continuous development of intelligent, integrated and automated technologies, green building technology will play a more important role in architectural design.

(2) New materials and policies and regulations have a profound impact on carbon emission management

In the future, the Engineering Management Department will prefer to adopt low-carbon materials such as renewable and carbon neutral. Carbon taxes, carbon trading schemes and green building certification systems will enable project teams to balance carbon emissions with economic benefits. These mechanisms incentivize the adoption of environmentally friendly materials and processes and optimize carbon emission strategies.

(3) Multi-policy guidance and promotion

Carbon emission control has become an important indicator of civil engineering management, and carbon emission optimization strategies are implemented throughout the life cycle of projects, intelligent building management systems and continuous monitoring mechanisms ensure that carbon emissions are monitored in real time, and strategies are adjusted to achieve targets.

5 Conclusion

With the growing challenge of global climate change, carbon emission management is becoming crucial in engineering management. Effective carbon strategies must be applied throughout the project lifecycle, from design and construction to operation. By using intelligent building management systems and continuous carbon monitoring, the Engineering Management Department can track emissions in real time and adjust strategies to meet targets. The future will see digital and intelligent construction as the main driver for carbon management. Integrating BIM, big data, AI, and IoT will enable real-time equipment monitoring, energy optimization, and precise emission control. The use of new low-carbon materials and stricter regulations will also support better decisions in material selection, cost control, and emission reduction.

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