Analysis of carbon emission reduction potential of construction industry in Liaoning Province based on system dynamics

Yitong Sun and Lihong Li*

School of management, Shenyang Jianzhu University, Liaoning, China

*Corresponding author e-mail: 413529784@qq.com

Abstract. The rapid increase in carbon emissions is one of the main causes of environmental degradation, and the construction industry contributes 40% of carbon emissions. This paper uses system dynamics to analyze the carbon emission reduction potential of construction enterprises in Liaoning Province in order to realize the national "dual carbon" goal as soon as possible. First, the factors affecting carbon emissions are summed up by combining the calculation formula of carbon emissions of buildings in the whole life cycle and related literatures. Then use the environmental characteristics of Liaoning Province to establish a carbon emission reduction model, carry out simulation simulation and validity test, and obtain the relationship between the influencing factors and carbon emission reduction. Finally, a scenario analysis is carried out in four aspects: energy technology, building materials production technology, transportation technology and waste recycling technology. A series of conclusions are drawn, such as building materials production technology and energy technology are the key aspects of implementing carbon emission reduction in the construction industry in Liaoning Province. The whole work provides a theoretical basis for Liaoning Province to successfully achieve the "14th Five-Year" goal, and then achieve carbon emission reduction and sustainable development.

Keywords: Construction industry in Liaoning Province; Carbon emission reduction; System dynamics; Simulation.

1. Introduction

President Xi Jinping proposed that China should strive to achieve a peak in carbon dioxide emissions by 2030, and strive to achieve carbon neutrality by 2060 [1]. The goal is the driving force. If we want to successfully achieve the double carbon goal, we must first take measures against industries with high carbon emissions. The construction industry is one of the industries with the highest energy consumption in the world, and a large amount of carbon is generated during the building life cycle. People must start to pay attention to the carbon emission of the construction industry [2]. In March 2022, the "14th Five-Year Plan" of Liaoning Province pointed out that by 2025, prefabricated buildings will account for 30% of the new construction area, and green buildings will account for 100% of the new urban construction area. At the same time, it is necessary to control building carbon emissions in the construction stage in terms of building material manufacturing and energy use structure [3]. With the acceleration of urbanization, the state pays more and more attention to building renovation work. In order to implement the deployment of the Party Central Committee, Liaoning Province proposed the "1358 Work Law" to guide the province to speed up the renovation of old communities. The problem that buildings need to be demolished and rebuilt will generate huge carbon emissions [4].

In the research on the carbon environment of the construction industry at home and abroad, most of them focus on the calculation and analysis of carbon emissions. Chen Jianghong et al. analyzed the energy consumption of residential buildings in the whole life cycle, and proposed the main types of data required for the necessity of establishing a large-scale statistical database, which laid the foundation for subsequent research [5]. Based on China's data from 2000 to 2015, Wu, P et al. evaluated the carbon emissions of the construction industry from the perspective of the whole life cycle, and finally put forward a useful scientific basis for the realization of carbon emission goals of the construction industry [6]. Banu Sizirici et al. explored the source of the carbon footprint of buildings from design to operation, and finally found that they can help customers get more carbon-reducing operations at different stages [7].

Most of the models are established based on exploring the source of carbon emissions, and the conclusions are relatively general, not entirely based on the actual perspective of carbon emission reduction. Song Xiangnan et al. proposed an optimal carbon emission reduction strategy based on the dynamic environment of the construction industry in the context of carbon trading by building a multi-objective optimization decision-making model, which is mainly oriented to government policy issues [8]. Xiancun Hu et al. took a two-step approach to discuss productivity based on a case study of the Australian construction industry, and then generate indicators of sustainable development and carbon reduction [9]. Y.Y. Feng et al. used system dynamics to simulate the trends of energy consumption and carbon dioxide emissions in Beijing from 2005 to 2030, and finally came to relevant conclusions on energy structure and energy consumption [10].

To sum up, most of the current literature on carbon emissions in the construction industry is based on the research of carbon emission sources and predicted carbon emissions at the national level, and does not propose targeted carbon reduction policies based on regional characteristics. As an old industrial, environmental pollution and resource depletion are the currently main problems in Liaoning Province. Urban transformation and sustainable development are the future development direction of Liaoning Province. In view of the literature on the whole life cycle, more attention is paid to the carbon emissions of buildings in the operation stage. This paper focuses on the production stage, transportation stage, construction stage and demolition stage of building materials. The system dynamics model for the analysis of the carbon emission reduction potential of the construction industry in Liaoning Province was developed, and the factors affecting the carbon emission reduction of the construction industry were comprehensively identified with the help of the system dynamics simulation tool Vensim software. The composition source and evolution path of emission, and then some scientific and reliable carbon emission reduction strategy are obtained, which provides a decision-making basis for the further realization of carbon emission reduction in the construction industry of Liaoning Province.

2. Construction of the system dynamics model for carbon emission reduction in the construction industry

2.1 Analysis of carbon emission reduction factors

System dynamics points out that the structure of the system is a dynamic feedback structure, which can be studied by the method of cybernetics. The factors affecting the carbon emission of the construction industry in Liaoning Province and the degree of influence of each factor have always been in a dynamic system. This paper summarizes the influencing factors and systems of carbon emission reduction in Liaoning Province based on the building carbon emission calculation standard [11]. It mainly analyzes the carbon emission reduction potential of the construction industry in Liaoning Province from the perspectives of five systems: economy, policy, energy, management and technology.

The carbon emissions studied in this paper should be the sum of the emissions in the production, transportation, construction and demolition stages of building materials. The specific formula is as follows:

$$C_{JC} = \frac{C_{SC} + C_{YS} + C_{JZ} + C_{OC}}{A} \tag{1}$$

Among them, C_{JC}——Building carbon emissions per unit floor area (kgCO2/m2); C_{SC}——carbon emission in building materials production stage (kgCO2); C_{YS}——carbon emission in building material transportation process (kgCO2); C_{JZ}——unit construction area in building construction stage carbon emissions (kgCO2/m2); C_{OC}——carbon emissions per unit building area in the building demolition stage (kgCO2/m2); A——cumulative building area(m2).

Through the formula, the influencing factors such as the energy carbon emission coefficient can be obtained around carbon emissions, but there are no factors that can intuitively show the carbon emission reduction. Therefore, this paper combines the Kaya identity and other related literature to summarize the construction industry in Liaoning Province. The carbon emission reduction system in the construction and demolition stages is divided into five systems: economy, policy, energy, management, and technology. The specific influencing factors are shown in Table 1.

Table 1 Subsystems and their Influencing Factors

Subsystem	Influencing factors
Economic subsystem	Liaoning Province's financial investment budget, The increase in technological innovation investment, The funds used for environmental problems, The secondary industry expenditure.
Policy subsystem	Government policy support, Economic structure.
Energy subsystem	Reduction in building energy consumption, Reduction in energy consumption, Increase in the proportion of clean energy, Carbon emission factor of building materials, Total construction energy.
Management subsystem	Capital investment structure, Recycling reduction, Transportation distance, Waste recycling reduction, Traffic reduction during construction, Building material consumption.
Technical subsystem	Increase in technology level, Increase in energy efficiency, Increase in production efficiency of building materials, Carbon emission factor per unit transportation distance, Energy carbon emission factor.

2.2 Model Causality Diagram

This paper analyzes the causality of the main factors affecting carbon emissions by comprehensively considering the complex relationships among economic subsystems, policy subsystems, energy subsystems, management subsystems and technology subsystems, and combining the development characteristics and social status of Liaoning Province. The result is shown in Figure 1.

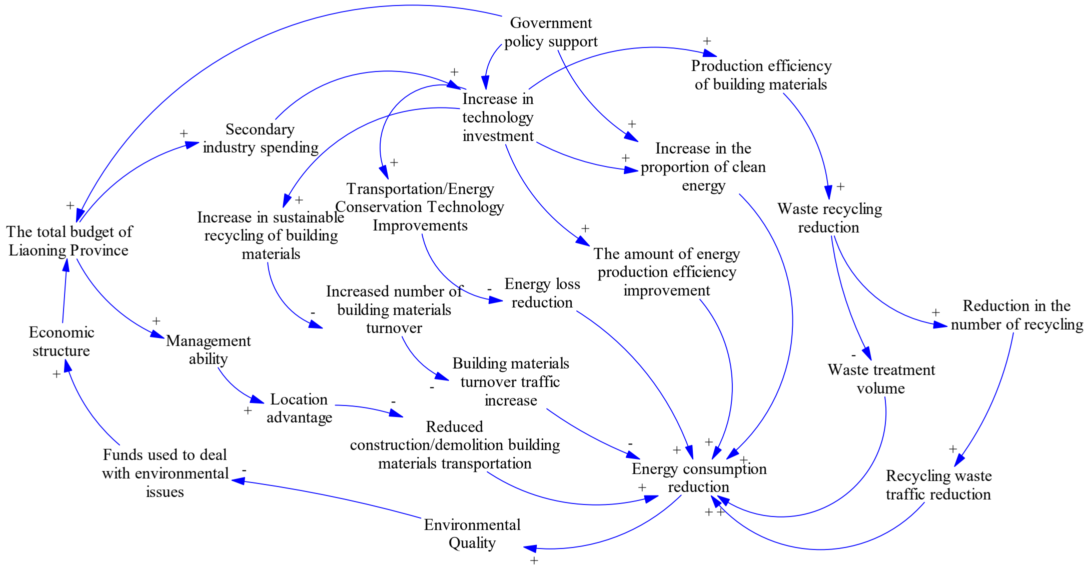

Figure 1 Causality diagram of carbon emission reduction of construction industry in Liaoning

1. Liaoning Provincial Financial Budget→+Secondary Industry Expenditure→+Increase in Technical Funding→+Building Material Production Efficiency→+Reduction in Waste Recycling→+Reduction in Recycling Times→+Reduction in Traffic for Recycling Waste→+Reduction in

Energy Consumption→+Environmental quality→+Funds used to deal with environmental problems →+Economic structure→+Financial budget of Liaoning Province.

2. Government policy support→+ Liaoning provincial financial budget→+ Secondary industry expenditure→+ increase in technology funding→+ Increase in the proportion of clean energy→+ Decrease in energy consumption→+ Environmental quality→+ Funds for environmental issues→ +Economic structure→+Financial budget of Liaoning Province.

3. Liaoning Provincial Financial Budget→+Management Capability→+Location Advantage→ +Construction/Demolition of Building Materials and Transportation Reduction → +Energy Consumption Reduction→+Environmental Quality→+Funds for Environmental Issues Treatment→ +Economic Structure→+Liaoning Province budget.

4. Liaoning Provincial Fiscal Budget →+ Secondary Industry Expenditure →+ Increase in Technical Funding →+ Increase in Sustainable Recycling Building Materials →+ Increase in Turnover Times of Building Materials →+ Increase in Building Material Turnover Traffic →- Reduction in Energy Consumption →+ Environmental quality→+Funds used for environmental problems→+Economic structure→+Financial budget of Liaoning Province.

2.3 Model stock-flow diagram

Based on the drawing of the causal relationship diagram, a series of carbon emission sources and implementation mechanisms for carbon emission reduction in the construction industry in Liaoning Province were initially obtained. The system comprehensively considers five subsystems, and puts building materials production, transportation, and construction and demolition stages in the same model to represent the carbon emission reduction implementation steps of each step in the entire life cycle of the building. More detailed indicators such as carbon emission coefficients have drawn stock-flow maps.

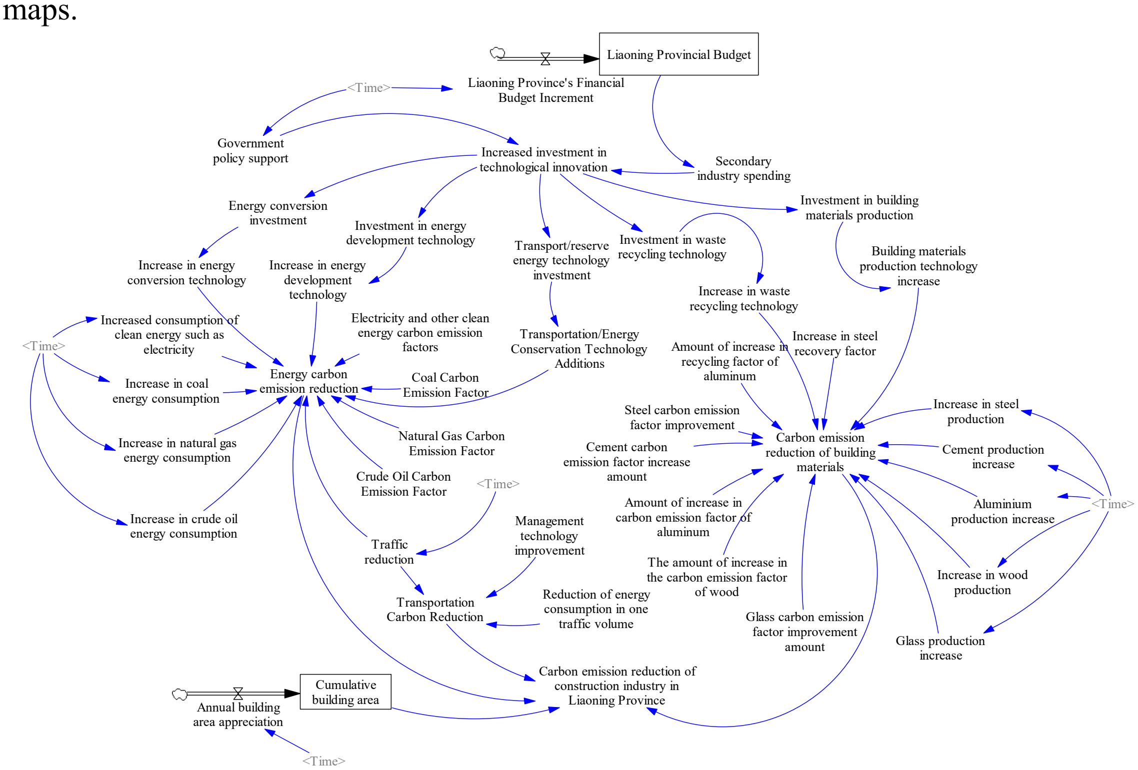

Figure 2 Stock-flow maps of carbon emission reduction of construction industry in Liaoning

3. Model simulation and verification

3.1 System parameters and sources

According to the relationship between the variables in the above stock-flow diagram, the simulation of the carbon emission reduction of the construction industry in Liaoning Province is carried out. The data of Liaoning Province's financial budget, secondary industry expenditure, cumulative construction area, annual construction area appreciation, and economic structure in this paper are mainly obtained from the "Liaoning Provincial Statistical Yearbook"; The proportion of coal, oil and natural gas consumption is mainly obtained from the "China Energy Statistical Yearbook"; The carbon emission coefficients of energy sources are based on the carbon emission coefficients published by IPCC [12], and the carbon emission coefficients of building materials are followed by Feng Bo [13].

3.2 System Simulation

According to the above parameters, the above variables and their interrelationships and the values of the parameters are input into the system dynamics software Vensim, and the simulation results are shown in Table 2:

Table 2 Simulation results

Time	Energy carbon emission reduction	Carbon emission reduction of building materials	Transportation Carbon Reduction	Liaoning Province Carbon Emission Reduction	Cumulative building area
2010	-365.53	-3269.53	26.62	-3608.44	139.1
2011	-328.57	-3263.52	23.53	-3568.56	151.98
2012	-429.74	-2727.84	19.52	-3138.06	151.98
2013	-126.64	-4053.43	28.35	-4151.72	151.98
2014	385.84	-1362.75	24.63	-952.28	151.98
2015	574.95	1264.35	16.26	1855.56	151.98
2016	462.85	3362.73	10.25	3835.83	163.09
2017	325.75	4178.25	13.95	4517.95	163.09
2018	146.36	4637.73	9.35	4793.44	165.08
2019	157.63	3959.25	21.95	4138.83	165.08

The simulation results of the system show the trend chart of each variable, as shown in Figure3,4,5,6.

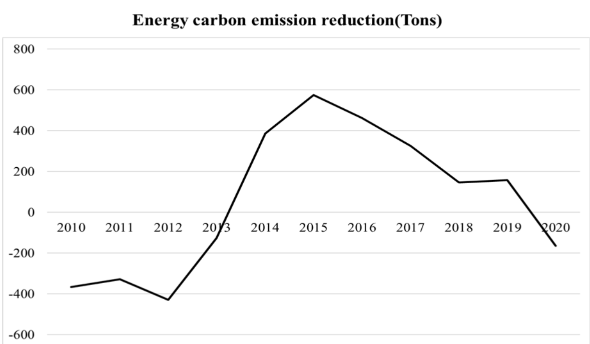

Figure 3 Energy carbon emission reduction

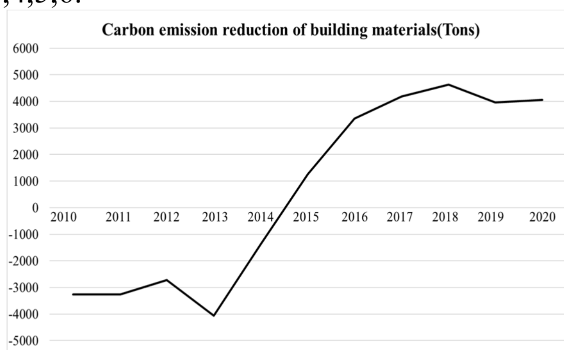

Figure 4 Carbon emission reduction of building materials

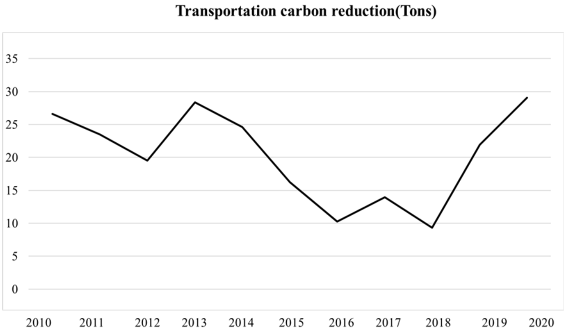

Figure 5 Transportation carbon reduction

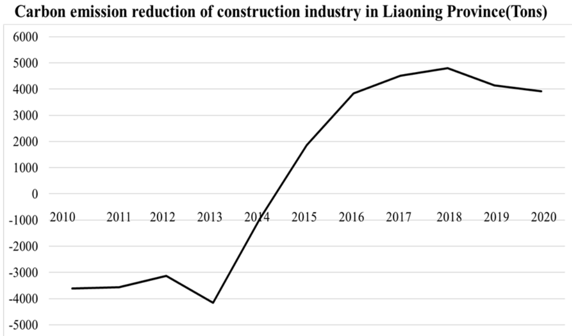

Figure 6 Carbon emission reduction

By comparing the carbon emission reduction trend map of the construction industry in Liaoning Province with the trend map of energy carbon emission reduction, building materials carbon emission reduction and transportation carbon emission reduction, it is found that the trend of carbon emission reduction in the construction industry is more consistent with the trend of carbon emission reduction in building materials. The majority of carbon emissions from the construction industry in Liaoning Province are contributed by the production of building materials, accounting for 70% of the total. Liaoning Province's "Twelfth Five-Year Plan" was completed, and the Liaoning Province construction industry's policy of focusing on adjusting the energy consumption structure and vigorously using clean energy has been initially implemented. During the whole life cycle of the building, a great number of policies such as the development of prefabricated buildings and the introduction of green buildings have greatly improved the carbon emission reduction of the construction industry in Liaoning Province.

3.3 Validity check

In order to test the authenticity of the model, this paper will test the validity of the obtained carbon emission reduction model for the construction industry in Liaoning Province. The simulation results are compared with the actual data values, and the validity of the model is judged by the error size analysis. In this paper, the indicator of carbon emission reduction in the construction industry in Liaoning Province is selected for historical testing.

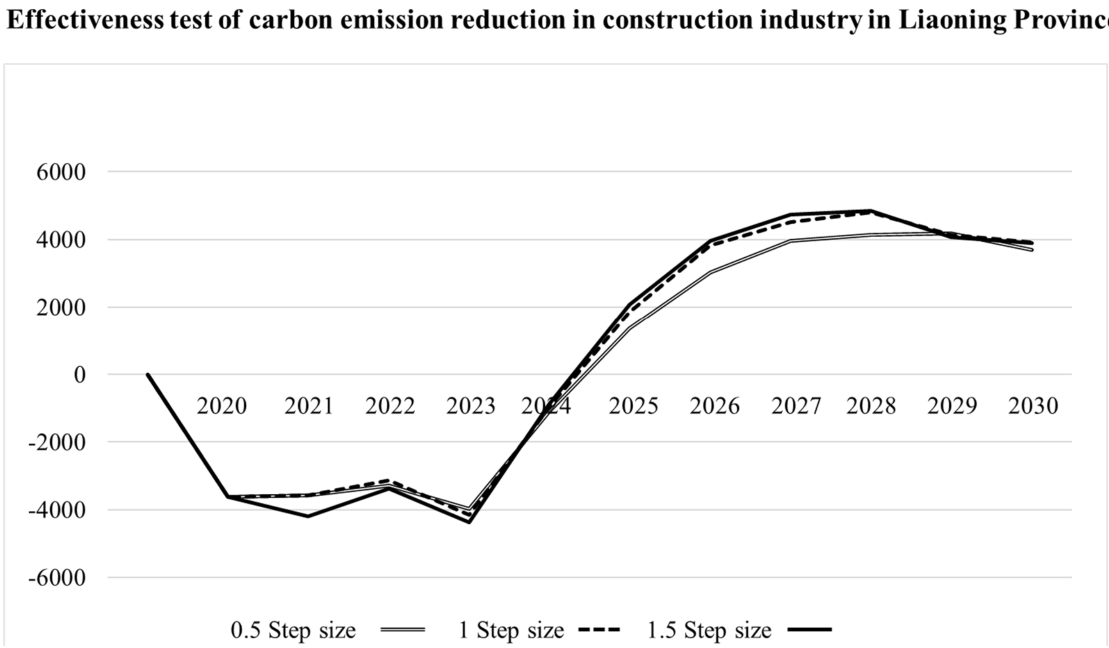

Figure 7 Validity test results

Through comparative analysis, it is found that the simulation errors of the variables are all controlled within 10%, which is in line with the 15% error allowable range of system dynamics. In the test of different step lengths, this paper selects the simulation values of 0.5, 1, and 1.5, which are three different step lengths, for the running test. The simulation results are shown in Figure 7. According to the results shown in the figure 7, when the simulation step size changes, the final result of the model does not change greatly. It shows that the model has passed the running test, so the model is stable and feasible.

4. Scenario Analysis and Forecast

In order to fundamentally solve the problem of high carbon emissions in the construction industry in Liaoning Province, a detailed carbon emission reduction plan has been formulated in combination with regional characteristics. In this paper, the scenario analysis method is adopted, and the control variables are used to carry out weighted restrictions in four aspects: energy technology, building material technology, transportation technology and recycling technology, and the improvement degree of each factor is the same. And only the carbon emission reduction is considered to be affected by factors such as technological investment, technological improvement, transportation volume and energy structure.This paper will conduct an in-depth analysis of the above indicators, divide it into five situations (including the original situation), and then obtain the relevant principles of the carbon emission reduction of the construction industry in Liaoning Province, and attempt to obtain the ranking of factors affecting the carbon emission reduction of the construction industry. It provides a theoretical basis for the formulation of the next carbon reduction plan for construction enterprises and the government in Liaoning Province. The specific scenario simulation results are shown in Figure 8.

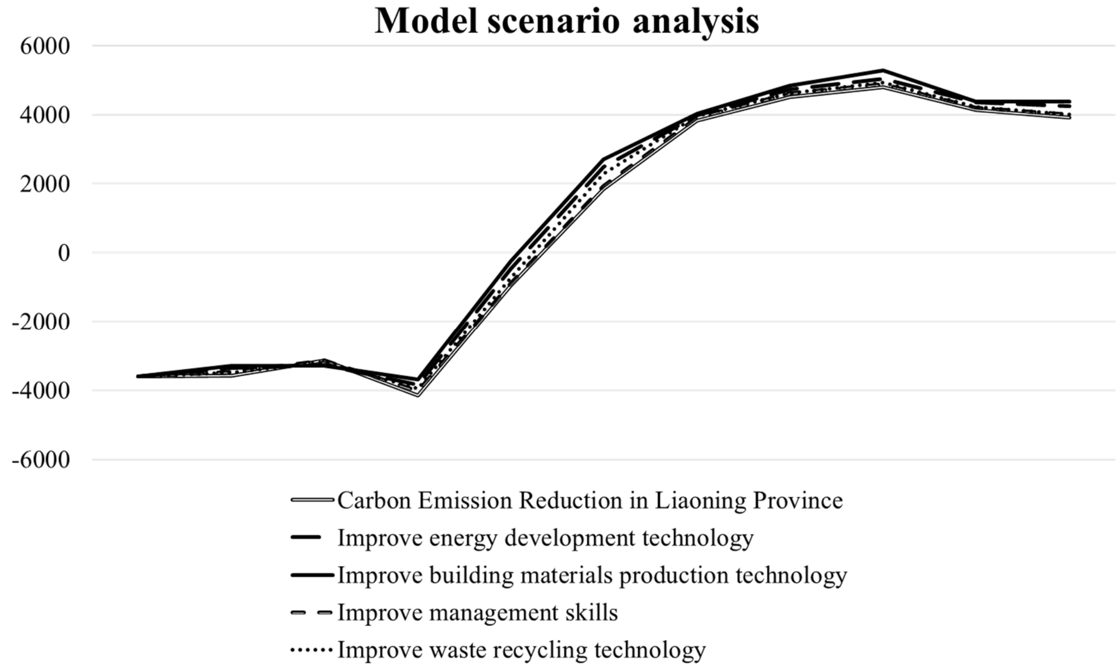

Figure 8 Scenario analysis results

The results show that building materials technology and energy technology have the greatest impact on carbon emission reduction in the construction industry. On the premise that all technologies are improved to the same extent, the improvement of building materials technology and energy technology can make the carbon emission reduction of construction enterprises in Liaoning Province the largest. In 2030, it can reach 4252.84 t and 4373.94 t, which can be reduced by 334t and 455.1t compared with the original situation, which shows that through the adjustment of energy structure, the improvement of energy conversion technology and the improvement of building material production capacity, the carbon emissions of the construction industry can be reduced to the greatest extent. It is the most carbon reduction measure that should be taken at present. According to statistics, only improving the two technologies of energy and building materials can preliminarily achieve the carbon emission target in the "14th Five-Year Plan" of Liaoning Province in 2025 and complete the national task.

5. Conclusion and suggestion

This paper uses system dynamics to conduct a simulation study on the carbon emission reduction potential of the construction industry in Liaoning Province. The results show that building materials production has the largest space in reducing carbon emissions in the construction industry, followed by energy, and finally transportation and management. The following conclusions and recommendations are obtained.

1) Develop energy development technology to reduce energy waste. Energy is a major issue for Liaoning Province, and cities such as Anshan and Fushun have been rated as resource-exhausted cities [14]. The rational use of remaining resources and the advancement of new energy development and development technologies are the direction that Liaoning Province should strive for.

2) Improve the production technology of building materials and maximize the conversion of energy. The production of building materials is an important part of the carbon emissions of the construction industry in Liaoning Province. By improving the production technology of building materials, energy can be converted to the greatest extent, and carbon emission reduction can be achieved from the source. Liaoning Province itself is relatively slow to respond to energy saving and low carbon. In the past decade, it has still used many traditional high-energy building materials. This also shows that Liaoning Province has a huge potential for carbon emission reduction in building materials production, which is the future. areas to focus on.

3) Strengthen the management ability of construction enterprises and optimize the construction site selection. The location of construction and material collection can directly affect the amount of traffic and the use of tools, resulting in huge carbon emissions. When writing feasibility reports of construction plans, construction companies should consider the constructability of the selected land in terms of distance, local resources, etc., minimize the amount of transportation and the use of tools and tools, and indirectly reduce carbon emissions.

4) Adjust the energy structure and upgrade and transform the construction industry. Relying on abundant coal resources, Liaoning Province did not consciously adjust the energy structure, resulting in a large amount of carbon emissions and an ecological and environmental crisis. By adjusting the energy structure, reducing the proportion of fossil energy use, vigorously developing clean energy, and using low-energy-consumption renewable energy, carbon emission reduction can be fundamentally and substantially carried out. As an old industrial base, Liaoning Province has always had the disadvantage of backward industrial structure and high production energy consumption, but the construction industry has an unshakable position as a livelihood project. For smart construction sites, the government has issued policy support while increasing the investment in scientific research funds of construction enterprises, promoting the continuous development of new technologies and patents for energy utilization, and thus achieving the goal of carbon emission reduction in Liaoning Province.

5) Strong support for prefabricated buildings, focusing on management during construction and demolition. The prefabricated type can not only greatly save human resources and building materials, shorten the construction period, but also avoid the secondary emissions of carbon elements caused by later maintenance and refurbishment. Material transportation and recycling during construction and demolition also account for a large proportion of carbon emissions from the construction industry in Liaoning Province. Manufacture sustainable and efficient building materials, increase their reuse in the same project, and improve their utilization. At the same time, scientific research funds are invested in the development of waste recycling technology. Until 2020, there is no obvious awareness of waste recycling and reuse in Liaoning Province. The remaining construction waste will become a hidden danger of carbon emissions in the future. By developing building materials recycling technology, the maximum retention for the usable part of the material, properly dispose of the waste part to reduce carbon emissions.

6) Focus first on sustainable building materials production, and then on energy and management issues. According to the results of the model and simulation analysis, it can be concluded that under the support of the environmental characteristics of Liaoning Province, the improvement of building

materials production technology, the development of energy technology and the improvement of the level of waste recycling technology have the most development potential. Can make a huge contribution to carbon emission reduction. However, considering the current economic strength and objective conditions of Liaoning Province, it is relatively difficult for Liaoning Province to develop new technologies such as waste recycling from scratch. Liaoning Province should focus on efficient production of building materials and new energy sources. In terms of technology development, combined with the successful experience of other regions, carbon emission reduction can be efficiently achieved in a short period of time. At the same time, the carbon emission base of Liaoning Province is high, and it still has an increasing value in enterprise management and energy conservation in transportation. The Liaoning provincial government should also take a long-term view and invest some funds in these two aspects for technological development and enterprise structure adjustment. While realizing the sustainable development of the city, the national carbon emission reduction task will be successfully completed.

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