Research on the uncertainty of low-carbon environmental governance system and its impact on the dual goals of carbon emission reduction

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Abstract

Based on the theoretical analysis of different dimensions of China's low-carbon governance environment, the uncertainty index of the low-carbon governance environment is constructed, and the fuzzy comprehensive evaluation of China's low-carbon governance environment is carried out based on the improved analytic hierarchy process and an entropy weight method. The dynamic panel model and PSTR transfer model are established to divide the degree of environmental uncertainty in low-carbon governance and to explore the regional heterogeneity impact of environmental uncertainty on the dual goals of carbon emission reduction. The empirical results show that as the uncertainty of the low-carbon governance environment changes from a low-zone system to a high-zone system, its negative impact on the realization of the dual goal of carbon emission reduction is gradually strengthened. The uncertainty of low-carbon governance environment will hinder the realization of China's carbon emission reduction targets. Stable low-carbon policy environment and economic environment are conducive to promoting carbon emission reduction targets from environmental governance, while the stability of technological innovation environment and carbon trading mechanism is an important factor in promoting carbon emission reduction targets.

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1. Introduction

The construction of a low-carbon governance system for the ecological environment is a complex systematic problem. Low-carbon governance is a comprehensive concept that integrates multiple subjects and multiple measures. China is in the transition period of a low-carbon economy. It is necessary to form a good low-carbon governance environment, establish scientific arrangements, and form a government-led cooperative linkage mechanism. At present, China actively promotes a multi-dimensional low-carbon governance network based on government, enterprises, and social organizations, and gives full play to the important role of government, market, enterprises, and other subjects in low-carbon governance to achieve environmental "good governance", and has achieved certain results (Dressel et al., 2020). In the process of low-carbon governance in China, long-term, comprehensive, and holistic planning should be formulated to form effective and complete governance tools and achieve goals. However, at the same time, in the process of low-carbon governance, China faces multiple uncertainties such as political, economic, technological, and market environment. Entering the "14th Five-Year" period, low-carbon environmental governance will face the inflection point of the environmental Kuznets curve. The late industrialization, the information revolution, and the new urbanization will have a coupling effect (Ayostina et al., 2022). Low-carbon environmental governance faces the problem of environmental uncertainty superposition (Ko et al., 2019). At present, the environmental governance in some regions of China is characterized by governance failure caused by premature, exogenous, formal, and vulnerable (Chu et al., 2022). In the process of environmental governance in China, there are internal structural defects of incomplete governance subjects (Lu et al., 2020).

Although there is no unified definition of environmental uncertainty in low-carbon governance, existing research has examined the impact of environmental uncertainty on technological innovation (Mallinson & Shafi, 2022), economic development (Kokkinos et al., 2021) and carbon emission reduction (Shao et al., 2022) from different perspectives, and discussed the impact of economic policy uncertainty on business investment and capital structure at the micro level (Wolfgang et al., 2021), and on trade, capital market and residents' consumption at the macro level (Liu & Dong, 2020). Based on the perspective of economic policy uncertainty, this paper analyzes the green effect of environmental regulation, and tries to explain the generation and mechanism of the "green paradox". In the study of low-carbon environmental governance, the existing research has made a deep interpretation of environmental governance from the perspectives of governance subject, governance system, and governance technology, and constructed the optimization path of environmental governance policy combination from the dimensions of dynamic mechanism, compensation mechanism, and supervision mechanism, to improve the performance of environmental governance. Starting from the governance subject, Wu et al.,(2022) pointed out the key participants of low-carbon environmental governance and the impact of urban low-carbon environmental governance on enterprises. Multi-agent cooperative governance can enhance system openness. Eraydn and Ozatagan (2021) studied low-carbon governance policy tools that focus on governance practices, involving a variety of tools and participants across scale and time. We study the transformation governance of urban sustainable development, discusses the legal framework, funding sources, participants, and the number and types of partnerships, and summarizes the key issues in the stage of low-carbon transformation governance from the perspective of theory and practice. Starting from the governance system, the systematic governance of a low-carbon environment can enhance the system's relevance and improve the system's integrity with source governance. The environmental governance policy mix will become an important path of environmental governance in China in the future. Peng et al. (2020) focused on the effect of environmental governance policy combinations in the Yangtze river economic belt to find the optimal policy combination. The low-carbon governance system is constructed from five aspects: energy conservation and emission reduction, development of new energy, reforestation, development of circular economy, and industrial structure adjustment. The laws and regulations, industry standards, and fiscal taxation are analyzed. From the perspective of governance technology, the balance of the system should be improved by precise governance, and the self-organization of the system should be improved by intelligent governance. For energy-intensive industries, stricter energy efficiency standards should be implemented to promote the introduction of more climate-friendly technologies (Lundmark & Pettersson, 2012; Chen & Kettunen, 2017). Industry standards should have strong legal support for accountability to ensure their full applicability in uncertain environments (Wang & Chang, 2014; Rotondo et al., 2020). The above research provides important enlightenment for this paper to explore the impact of the uncertainty of a low-carbon governance environment on the dual goals of carbon emission reduction.However, at the same time, research perspective focuses on the uncertainty of economic policy, with environmental regulation as the main object, focusing on the impact of policy changes on low-carbon environmental governance, ignoring the impact of uncertainty on carbon emission reduction under the dynamic development of the economic environment, technological innovation environment and carbon emission trading market in the process of low-carbon governance. Low-carbon governance gradually showed a multi-dimensional, diversified development trend, which led to an increasingly complex low-carbon governance environment. Low-carbon environmental governance is long-term and complex, and there is a contradiction between emission reduction governance and the negative externality of carbon emissions. Strengthening the construction of a low-carbon environmental governance system is an important decision for the global response to climate change and can form the basis for future national competitive advantages. How to improve China's low-carbon environmental governance system is an important issue for the continuous improvement of government functions, economic policies, technical means, and market systems in the construction of ecological civilization. Therefore, a comprehensive analysis of the impact of uncertainty of low-carbon governance elements on carbon emission reduction will help to accelerate the establishment and formation of a strategic framework and planning system for the development of a low-carbon economy and effective management.

Therefore, in this paper, we first explain the mechanism of environmental uncertainty of low-carbon governance affecting emission reduction performance theoretically. Then, based on the panel data of 30 provinces in China, we construct a dynamic panel model and use the PSTR model to analyze the linear and nonlinear effects of environmental uncertainty of low-carbon governance on total carbon emissions and carbon emission intensity. The marginal contribution is to overcome the current focus on the macroeconomic policy environment while ignoring the dynamic effects of the economic policy environment, innovation environment, and the development of carbon emission trading under low-carbon governance, as well as the overall grasp of the ecological environment under low-carbon governance and its correlation with carbon emission reduction targets. The defects of the research further explore the uncertainty of the ecological environment under low-carbon governance and its impact on the quantity and intensity of carbon emissions from the theoretical and experimental perspectives, thus verifying the low-carbon government environment, low-carbon business environment, policy environment, and carbon emission trading environment and carbon emission reduction. The correlation between the dual goals of reduction. It puts forward development suggestions for China's future stable economic government environment, development of low-carbon operation, promotion and establishment of a stable carbon emission trading market, to achieve China's carbon emission reduction targets.

2. Literature Review and Mechanism Analysis

In the process of low-carbon governance, China has gradually broken through the traditional unilateral governance model, aiming at playing the role of low-carbon collaborative governance. For the uncertainty of the environment, we combine the relevant research of scholars and the corresponding theoretical basis to obtain and identify the uncertainty factors in the process of low-carbon governance, which are divided into four aspects: the uncertainty of low-carbon policy environment, the low-carbon economic environment, the environmental uncertainty of low-carbon technology innovation and the uncertainty of carbon trading market. Analyze the impact and difference of the overall uncertainty of the low-carbon governance environment and the uncertainty of each dimension on carbon emissions, and analyze the emission reduction performance of each subsystem of the environment low-carbon governance system.

2.1. Low Carbon Policy and Emission Reduction Performance

The government can lead the whole process of low-carbon governance (Song et al., 2020). To achieve the goal of coordinated environmental and economic development, the Chinese government actively coordinates the macro and micro areas of low-carbon policies (Feng & Yu, 2013). Therefore, the policy environment has become an important environment for achieving carbon emission reduction targets (Jiang & Hao, 2022). The low-carbon policy implements structural low-carbon management through administrative intervention to improve energy consumption efficiency, thereby improving high energy consumption in industries such as electricity, transportation, and construction(Wei et al., 2020). Low carbon policy plays an important role in low carbon operation and production of high energy-consuming industries The uncertainty of a low-carbon policy environment is manifested in the uncertainty of policy formulation and policy implementation, which affects the efficiency of resource utilization, the improvement of energy utilization efficiency and the strengthening of environmental information disclosure. At present, there is uncertainty in the formulation and implementation of low-carbon policies, which leads to a high cost of policy supply and may even fall into the dilemma of low efficiency of incentive policies (Fan et al., 2021; Zhao et al., 2022).

Summarizing the environmental policy research, environmental regulations, environmental information disclosure system, social responsibility system, and other policy factors are the key means and driving forces for the government to achieve carbon emission reduction. The uncertainty of policy formulation has aroused widespread debate among scholars. From the perspective of the impact of policy completeness on emission reduction performance, a good policy environment is the core driving force for enterprises to actively promote carbon emission reduction. Kevin et al. (2020) discussed the impact of changes in environmental regulations on carbon emission reduction under the analytical framework of policy scenarios. The social responsibility system is an important guarantee for promoting environmental information disclosure and implementing emission reduction targets (Petcu et al., 2021). Therefore, a perfect environmental policy is an important factor to curb carbon emissions, and the important role of a carbon tax should be further emphasized. At the same time, decentralization harms China's carbon emissions. Under the decentralization system, local governments have selectively relaxed the supervision of some high-tax industrial enterprises, generated pollution income, and found increased sewage charges. This is not conducive to the realization of carbon emission reduction targets. In addition, fiscal decentralization increases the emission intensity of pure polluting public goods covering the whole country (Romano & Fumagalli, 2018).

The uncertainty of policy implementation is reflected in the uncertainty of the effectiveness of system implementation under low-carbon policy arrangements. Under fiscal decentralization, local governments will have more autonomy and initiative in the process of policy implementation. If the development goals of central and local governments conflict, local governments may lower environmental standards in the course of the game, gain benefits, and sacrifice energy consumption, thereby increasing the uncertainty of whether carbon reduction targets can be achieved. Good implementation of policies can improve resource efficiency and energy efficiency. Wang and Lei (2020) found that the change in local environmental protection department officials effectively promoted corporate environmental governance, and environmental regulations could reduce carbon emissions. The government imposes environmental taxes such as energy taxes and carbon taxes on fossil energy suppliers and consumers, increasing environmental and production costs, and thereby reducing the demand for low-carbon emissions (Reaos, 2020). Changes in officials of local environmental protection departments will affect the decisions of creditors, shareholders, and other stakeholders. The introduction will affect corporate charitable donations, corporate dividend policies, and corporate tax avoidance, and will have an impact on corporate capacity and carbon emissions from a longer-term perspective. At the same time, studies have found that changes in local environmental protection will also bring uncertainty to the implementation of environmental policies (Bevan, 2022).

2.2. Low Carbon Economy and Emission Reduction Performance

The environmental uncertainty of low-carbon economy is mainly manifested in the trade environment, investment and financing environment, management environment and other aspects are facing a certain degree of uncertainty, which makes the company's cash flow, bear the social responsibility, take the initiative to reduce emissions from the long-term changes, thus affecting the carbon emission reduction targets (Mayer et al., 2014). Economic development and carbon emissions are highly correlated (Sekrafi & Sghaier, 2016). The environmental uncertainty of a low-carbon economy is manifested in the impact on carbon flow and carbon emissions caused by the development of a low-carbon economy such as investment and financing and trade activities and regional green finance.

Under the investment transmission, foreign trade has become a favorable condition for releasing the "halo effect" of FDI on carbon productivity (Wang et al., 2019). Under the "producer responsibility principle", trade activities increase total carbon emissions. The openness of foreign trade is uncertain. At present, trade conflicts are escalating, and China is facing pressure in the process of stabilizing foreign trade and investment, resulting in the linkage of internal and external risks. Under the "pollution haven" hypothesis, some scholars have verified the adverse effects of FDI inflows and trade activities on carbon emission reduction. At present, "promotion theory", "inhibition theory", and "conditional promotion" are three types of views that analyze the impact of foreign trade on carbon emissions. The "promotion theory" holds that foreign trade can exert competitive and spillover effects to improve the efficiency of carbon emission reduction in the long run. Romano et al.(2018), a representative scholar of " inhibition theory, " conducted an empirical study using British firm-level data and found that the fierce competition caused by foreign investment is not conducive to carbon emission reduction. With the increasing degree of economic openness, the total amount of carbon emissions from trade activities continue to increase under the uncertain environment. The uncertainty of the current trade and investment environment may hurt emission reduction performance.

With interest rate volatility in capital markets, higher financing costs for high-emission companies are accompanied by increased demand for cash flow, accelerating resource extraction in the short term and possibly in the long term, resulting in higher total carbon emissions. The real options theory holds that if an investment is irreversible, investment opportunities are regarded as resources owned by economic entities. As the uncertainty of the macro investment environment increases, the value of options held increases, the net income of "waiting" increases, and the net income of investment decreases due to the increase of the marginal cost of economic entities, thus affecting carbon emission reduction.

At the same time, the rapid development of green finance has an inhibitory effect on the financing activities of high-emission enterprises. China's current green financial system still needs to be improved, and it faces new challenges in the process of carbon reduction transformation. While the development of green finance brings investment opportunities and development opportunities and potential financial risks are worth preventing. At the same time, the low-carbon economic environment also has a great impact on the business activities and growth of enterprises. Green finance promotes the low-carbon production of enterprises, thereby reducing the energy intensity and carbon emission intensity, and creating favorable conditions for enterprises to reduce carbon emissions (Gan & Voda, 2022). On the other hand, green monetary policy has greater restrictions on subsequent financing of high-emission enterprises, investors, and banks, increasing the risk premium of uncertainty and increasing the cost of external financing (Zheng & Zhu, 2021). By actively developing energy-saving technologies for enterprises, optimizing resource allocation, and improving emission reduction efficiency. Changes in the company's business income and costs lead to inaccurate predictions of future cash flows by the company's management, which affects the allocation of resources and the company's ability to generate cash. Corporate social responsibility is increasing, and the path of dependence on energy consumption is slowly changing. While pursuing economic development, the growth rate of total carbon emissions has slowed down. High-emission firms face strict requirements. Relevant policies have forced high-emission enterprises to reduce carbon emissions through technological innovation and other means, reducing their relative disadvantages in the green financial market(Wang et al., 2022).

2.3. Low Carbon Technology Innovation and Emission Reduction Performance

Low-carbon technology innovation is the key to achieving carbon emission reduction targets. Under the constraints of sustainable development goals, low-carbon technology innovation has become the reform direction of key energy-consuming industries. Power, steel, and other industries to actively implement low-carbon sustainable development goals, and low-carbon technology innovation systems to generate and develop carbon-neutral technology innovation support.

Through low-carbon technology, innovation means achieving total carbon emission control, actively developing new technologies in the production process, and transforming high-carbon links to reduce carbon emissions. In the process of achieving green development, the uncertainty of the low-carbon technology innovation environment makes the opportunities and challenges faced by high-emission enterprises coexist, which in turn affects emission reduction performance. China's low-carbon technology is facing a series of challenges, such as international competitive disadvantage, mid-end technology limitations, lack of common technology, and low efficiency of collaborative innovation.

First of all, with the policy tools such as intellectual property protection, the difficulty and cost of low-carbon technology transfer are increasing. At present, China's low-carbon technology is relatively weak compared with foreign leading technologies and is still in the stage of technological catch-up. The introduction process requires high licensing fees and royalties (Wang & Yang, 2020).

Secondly, mid-end technology lock-in is a combination of market preference and technological potential. Sub-optimal technology will crowd out the dominant technology and may appear lock-in effect, making technology uncertainty mainly manifested as a "technology-system lock-in" phenomenon, to adjust the impact of technology learning and management learning on the realization of low-carbon technology innovation in key links, and then have an impact on the dual goals of carbon emission reduction (Yang et al., 2017). Overall, in the face of competitive disadvantage and uncertainty in the international environment, enterprises weigh the risks and benefits of innovation activities. Mayer et al. (2014) believed that the uncertainty of the innovation environment can lead to the rise of R&D level of enterprises, and the positive effect of uncertainty is more intense in industries with difficult innovation and enterprises with high value.

Third, the lack of generic technology innovation subjects. The supply mode of generic technology in China's low-carbon field is mainly based on existing professional research institutes and advantageous enterprises. The core technology in the field of low carbon is an emerging technology in the exploratory research and development stage. High risk of technology research and development, investment. Some technologies include the integration of multiple technologies. A single enterprise or R&D institution often lacks strong financial strength and technical research. From the perspective of specific technology, under the carbon lock-in state, the path of industrial economic development depends on increasing returns, especially carbon-intensive fossil fuel energy systems. New energy planning and environmental protection policies involve the construction of generic technology supply institutions. In the process of emerging technology breakthroughs and technical standard formulation, the industrial alliance has become an important organizational form to jointly create a low-carbon economic development form. Therefore, due to the uncertainty of the technological environment, the low-carbon technology innovation process cannot give full play to the R&D cooperation and resource-sharing effect between enterprises, so it is not conducive to the realization of carbon emission reduction targets.

2.4. Trading Market and Emission Reduction Performance

The essential purpose of carbon emissions trading is to promote the sustainable development of a green low-carbon economy through market-oriented means (Lin & Jia, 2019). The identification and measurement of carbon trading market uncertainty is an important issue to promote the healthy development of carbon trading activities. The carbon emissions trading market solves environmental problems through "marketization" (Fwa et al., 2019). China's carbon trading market has been expanding since its establishment, and each pilot has shown different market transactions and performance status. In the future, the carbon trading market will continue to develop and improve to help achieve carbon neutrality and other emission reduction targets (Zhao et al., 2020). In addition to the supply and demand of the energy market, it is also vulnerable to the market regulation, market transaction activity, climate change, the quota allocation, and other factors, resulting in market uncertainty.

From an international perspective, the carbon trading system in developing countries is not perfect, and there is a lack of carbon finance professionals (Cheng et al., 2020). The benefit distribution pattern of the global carbon trading market is uncertain, and the market expansion is highlighted by the change of benefit distribution caused by the change of pricing power and discourse power. Europe and the United States are at the high end of the carbon market value chain, that is, the rule-making end. Enterprises face market competition and risks.

From the perspective of regional development, local governments are seeking to establish a cross-regional environmental impact assessment sharing mechanism and are promoting the co-construction of regional carbon emission trading markets. Carbon price stability leads to the stability of the carbon emission trading market, which has a positive impact on emission reduction performance. The degree of marketization and disclosure of corporate environmental information has a significant impact on emission reduction performance. The degree of marketization reflects the influence of resource allocation and market activity. When the degree of marketization is high, the transaction volume is large, and the market dominates the allocation of resources. The legitimacy of the environment is largely determined by non-market factors such as the government. In the process of building carbon emissions trading market in China, the carbon trading market is highly dependent on policy, compared to other financial markets, the carbon trading market is a more typically complex nonlinear system. China is faced with the objective uncertainty of establishing a carbon trading market and the challenge of the market mechanism. It has been found that there is heterogeneity in the market risk of the carbon trading quota market and project market, which makes the mode and stage differently.

Therefore, this paper forms the correlation mechanism between the environmental uncertainty of low-carbon governance and the dual goal of carbon emission reduction as shown in figure 1.

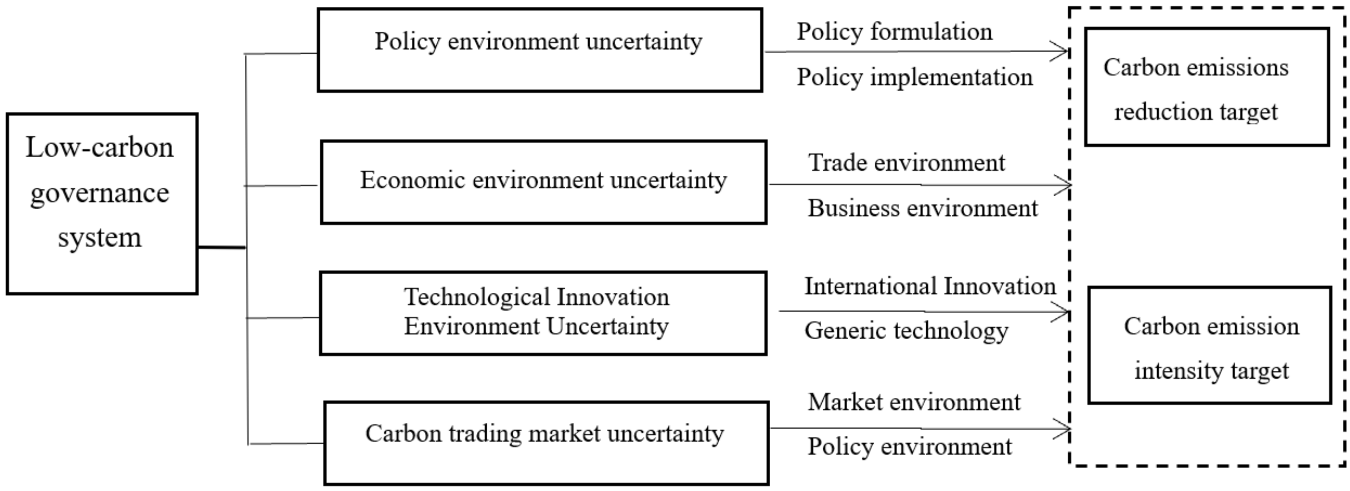

Figure 1. Correlation mechanism between low-carbon environmental governance system and dual goals of carbon emission reduction

After analyzing the correlation mechanism between the low-carbon environmental governance system and the dual goals of carbon emission reduction, the uncertainty of China's low-carbon environmental governance system and the uncertainty of each subsystem are measured. Establish a model for further investigation.

3. Research Design

3.1. Regional Low Carbon Governance Environment Uncertainty Measurement

3.1.1. Evaluation index system construction

The low-carbon environmental governance system refers to the environmental governance based on the principle of emission reduction, taking the environmental law as the criterion, taking the restoration of climate as the goal, integrating the synergistic effect between policies, implementing low-carbon technical means, and building a market-oriented mechanism to reduce carbon emissions. This emission reduction path is guided by carbon emission reduction, and constructs a low-carbon economic transformation mechanism and a multi-agent governance operation mechanism, to reduce the uncertainty of the governance environment and build an operating system for environmental governance by policy, economy, technology, and market. For the measurement of the uncertainty of the low-carbon governance environment, 19 evaluation indicators are set up based on the existing scholars' research on different dimensions of the low-carbon governance environment. Indicators set mainly follow the following four principles: First, the indicators have the principle of reliability, that is, the selection of indicators has a certain basis and theoretical basis; the second is the principle of sustainability, which can be compared in different years to observe the dynamic changes of different dimensions; the third is the principle of structural characteristics, that is, the selection of indicators can reflect the structure of low-carbon governance environment, to measure the uncertainty of different dimensions; Fourth, the index setting strives to be comprehensive, to reflect the complete low-carbon environmental governance system, to analyze the uncertainty of regional low-carbon governance environment from the perspective of the system.

For the uncertainty of the policy environment, the existing research is integrated to consider the policy environment from all aspects of low-carbon governance. From the regional environmental regulation, transparency of environmental information disclosure, the completeness of regional environmental policy, and the local officials' emphasis on low-carbon governance(Stephan, 2010; Wang et al., 2019; Cline, 2007). Regional environmental regulation intensity reflects the improvement of high energy-consuming industries by administrative intervention from the perspective of policy making. Transparency of environmental information disclosure can urge enterprises to actively promote carbon emission reduction and improve the efficiency of incentive policies in environmental information disclosure and management. The completeness of regional environmental policies reflects the government's motivation to achieve carbon emission reduction and forms the core driving force for enterprises to promote carbon emission reduction. Local officials ' emphasis on low-carbon governance reflects policy guidance and implementation effects to a certain extent. The uncertainty of policy implementation is reflected in the uncertainty of the effectiveness of system implementation under low-carbon policy arrangements.

The uncertainty measurement of the economic environment is measured from foreign trade, capital market, and green financial development(Chen et al., 2021; Huang et al., 2022; Chu et al., 2021). Foreign trade and capital markets accelerate the flow of cash flow through the investment and financing transmission mechanism, which changes the resource behavior of enterprises. The ' halo effect ' of carbon productivity is formed under the ' producer responsibility principle '.Green financial development affects the social responsibility and emission reduction initiative of high-emission enterprises by affecting the ability of resource and capital allocation.

The uncertainty of the innovation environment is measured from the perspectives of competitive advantage, technology mastery, and technological change(Hayes, 2012; Am et al., 2019; Falcone & Sica, 2019). In a complex competitive environment, mastering mid-end technology and common technology is conducive to achieving collaborative innovation efficiency among enterprises, moving from the technology catch-up stage to the competitive advantage stage, and breaking the "technology-system lock". With technological change, high-emission enterprises face both opportunities and challenges. Enterprises actively develop new technologies in the production process, from the co-evolution of technology and system, and realize the R & D cooperation and resource-sharing effect of low-carbon technologies.

To measure the uncertainty of the market environment, the construction capacity of the regional energy and environment exchange (Wang et al., 2021), the activity of participating in the carbon trading market (Trowman et al., 2021), the compatibility with the national carbon emission trading market (Lane et al., 2021) and the maturity of the carbon emission information management platform (Giannousakis et al., 2020) are selected to measure the uncertainty of the carbon trading market. In the typical complex nonlinear system of carbon trading market system, China faces the uncertainty of the establishment of a carbon trading market and the constraint of the market mechanism. Speeding up the construction of regional energy and environmental exchanges to a certain extent determines the construction process of the regional carbon emissions trading market and the degree of connectivity with the national carbon emissions trading market, through the "market" approach to achieve emission reduction targets. The improvement of the carbon trading system can improve market activity and use market expansion to seek cross-regional sharing mechanisms, to promote the co-construction of the regional carbon emissions trading market. Thus, the formation of a regional low-carbon governance environment uncertainty evaluation index system is shown in Table 1.

Table 1. Regional low-carbon governance environment uncertainty evaluation index system

Target layer	Standard layer	Operation layer
Low carbon governance environmental uncertaintyA	Policy environment uncertainty A_1	Regional environmental regulation intensity A_{11}
		Regional environmental information disclosure transparency A_{12}
		Completeness of Regional Environmental PolicyA_{13}
		Local environmental officials focus on low-carbon governanceA_{14}
		Regional fiscal decentralization degreeA_{15}
	Economic environment uncertaintyA_2	Regional foreign trade openness A_{21}
		The decoupling degree of regional economic development and carbon emissions A_{22}
		Regional Capital Market Stability A_{23}
		Regional green financial development level A_{24}
		Suppression of Green Finance on Investment and Financing of High Emission Enterprises A_{25}
	Innovation environment uncertainty A_3	Advantages and Position of International CompetitionA_{31}
		Mid-end technology locking degree A_{32}
		Mastery of Common TechnologyA_{33}
		Cooperative innovation efficiency stability A_{34}
		Speed of technological change in high energy-consuming industries in the regionA_{35}
	Market Environment Uncertainty A_4	Building capacity of regional energy and environment exchangeA_{41}
		Regional participation in carbon trading market activityA_{42}
		Compatibility with the National Carbon Emissions Trading MarketA_{43}
		Regional carbon emissions information management platform maturityA_{44}

3.1.2. Determining Index Weight

When comparing the indicators in pairs, if a_i and a_j are equally important, it is denoted as“1”; if a_i is more important than a_j, it is denoted as“2”; if a_i is not as important as a_j, it is denoted as“0” Accordingly, the initial judgment matrix, $A = (a_{ij})_{n\times n}$ is established, calculating the relative importance of each index, $r_i = \sum_{j=1}^{n} a_{ij}$, establish the judgment matrix, $B = (b_{ij})_{n\times n}$ where b_{ij} satisfies:

$$b_{ij} = \begin{cases} r_i - r_j + 1, & r_i \geq r_j \\ \left(r_i - r_j + 1\right)^{-1}, & r_i < r_j \end{cases}$$

Calculate the initial indicator weight according to Matrix B:

$$s_i = \bar{s}_i / \sum_{i=1}^{n} \bar{s}_i, \quad \bar{s}_i = \sqrt[n]{\prod_{j=1}^{n} b_{ij}}$$

The entropy weight method is used to modify the index weight to obtain the final index weight. Standardize the judgment matrix B to obtain a matrix $C = (c_{ij})_{n \times n}$, where $c_{ij} = b_{ij} / \sum_{i=1}^{n} b_{ij}$ .Calculate the information entropy weight of index i:

$$\lambda_i = \left(1 - e_i\right) / \left(n - \sum_{j=1}^{n} e_j\right)$$

where, $e_i = -\frac{1}{\ln n} \sum_{j=1}^{n} c_{ij} \ln c_{ij} (i = 1, 2, \ldots, n)$ is the information entropy of index i.

The final index weight is obtained by combining the index weight with the information entropy weight, namely:

$$w_i = \frac{\lambda_i s_i}{\sum_{j=1}^{n} \lambda_j s_j}$$

The calculation results are shown in Table 2.

Table 2. The weight of the operational layer of low carbon governance environment uncertainty evaluation index

Operation layer	A11	A12	A13	A14	A15	A21	A22	A23	A24	A25
Corrected weight	0.1021	0.0894	0.0783	0.0563	0.0214	0.0547	0.0531	0.0626	0.0236	0.0322
Operation layer	A31	A32	A33	A34	A35	A41	A42	A43	A44	
Corrected weight	0.0537	0.0323	0.0524	0.0125	0.0326	0.1158	0.0531	0.0600	0.0139	

3.1.3. Fuzzy comprehensive evaluation

Using a fuzzy comprehensive evaluation method to determine the evaluation factor set to establish a fuzzy set, quantitative indicators of membership and low-carbon governance of China's 30 provinces to evaluate the uncertainty of the environment.

First, a clear fuzzy comprehensive rating algorithm. The corresponding evaluation factors are expressed as U (low-carbon governance environment uncertainty) = {U_1(regional environmental regulation intensity),..., U_{10} (inhibition degree of investment and financing of high-emission enterprises),..., U_{19} (maturity of regional carbon emission information management platform)};

Secondly, the grade of comment is established and the elements are assigned: V= { V_1 (high) = 5, V_2(high) = 4, V_3 (medium) = 3, V_4 (low) = 2, V_5(low) =1}, corresponding to the elements U_i(i = l, 2,..., 19) in the evaluation factor set, the fuzzy evaluation of the sub-factor set is carried out.

Third, quantitative index membership. The intensity of environmental regulation, the degree of fiscal decentralization, and the degree of foreign trade in the operation layer can be obtained through data statistics and calculation, which are quantitative indicators. In terms of the measurement of the intensity of environmental regulation, most of the domestic-related research uses the proportion of total investment in industrial pollution control to industrial added value or the operating cost of pollution control facilities to measure the intensity of regulation. Some studies reflect the government's "regulatory willingness" by the number of environmental legislation, the number of environmental cases, and the number of environmental policies.

Based on the existing research, the intensity of environmental regulation is measured by the logarithm of the number of environmental policies. In the measurement of the degree of foreign trade openness, calculate the total import and export trade as a share of GDP; for the measurement method of fiscal decentralization, the per capita fiscal expenditure in the provincial budget / per capita fiscal expenditure in the central budget is used to measure the degree of regional fiscal decentralization. For the above three quantitative indicators, the average segmentation method is used to divide the membership degree, and the extreme values (1,5) at both ends of the index grade interval are set, so that the index interval is divided into three sections on average, corresponding to the established comment grades (2,3,4), and other indicators are qualitative indicators.

Fourth, get a fuzzy comprehensive evaluation score. According to the expert scoring, the fuzzy evaluation matrix is constructed, and the first-level index score is accumulated according to the product of score and weight. The comprehensive evaluation vector is calculated to obtain the overall evaluation score of low-carbon governance environment uncertainty. The uncertainty of the low carbon governance environment can be preliminarily determined according to the judgment set.

3.2. Variable selection and data description

3.2.1. Variable selection

1. Uncertainty of low-carbon governance environment (X), measured by the fuzzy comprehensive evaluation score of regional low-carbon governance environment uncertainty.
2. Dual carbon emission reduction targets (C), measured by total carbon emissions (CT) and carbon intensity (CI).

3. Control variables: According to the total carbon emission influencing factors of the Kaya equation, the provincial population (*P*), total economic output (*E*), two-way FDI (*FDI*), industrial structure (*IN*), and energy structure (*ES*)are used as control variables.

3.2.2. Data description

Since China's carbon emission trading pilot market has been established in 2011, the sample period selected in this paper is the panel data of low-carbon policy, economy, technology, and carbon trading market in 30 provinces of China from 2011 to 2019. Among them, the data of the low-carbon governance environment uncertainty (*X*) variable are measured by the evaluation results of the low-carbon governance environment uncertainty evaluation index system constructed above, and other variables are obtained by further processing the public data. The data are standardized to be within [0,1], overcoming dimensional differences. The data come from China Energy Statistical Yearbook (2012-2020), 'China Statistical Yearbook (2012-2020)' and 'regional statistical yearbooks'. Table 2 lists the mean, standard deviation, and correlation coefficient of each variable. According to the data in the table, there is a certain correlation between variables, and the correlation coefficient is not very high. Further calculation of the variance expansion coefficient (V1F) of the variable, the results show that the variance expansion coefficient of each variable is less than 2, far below the critical value of 10, and there is no serious multicollinearity problem.

Table 1. Correlation analysis of variables

Variable	1	2	3	4	5	6	7	8
X	1	—	—	—	—	—	—	—
CT	0.1360	1	—	—	—	—	—	—
CI	0.1524	0.1142*	1	—	—	—	—	—
P	0.0154	0.1070	0.0646	1	—	—	—	—
E	0.0063	0.0518	0.0433	0.3611	1	—	—	—
FDI	0.0425	0.0445	0.0496	0.2422	0.2031	1	—	—
IN	0.2241	0.0326	0.0204	0.2164	0.1059	0.3500	1	—
ES	0.1158*	0.0593	0.0598	0.3751	0.1876	0.3239	0.1374	1

*Note: *, **, *** are significant at 10%, 5% and 1% significance levels, respectively.*

3.3. Model setting

3.3.1. Dynamic panel model

In the process of low-carbon governance in China, the dual regulation of total carbon emissions and carbon emission intensity is deeply influenced by the current economy, policy, market, and technological situation. The change in the governance environment is reflected in the evaluation results of uncertainty, which may lead to endogenous problems. At the same time, the historical total carbon emissions and emission reduction targets may affect the current emission reduction performance, the introduction of dynamic model lag to control the lag factors. The SYS-GMM method is used to estimate to solve the endogenous problem and capture the long-term and inertial characteristics of China's low-carbon governance. The dynamic panel model is constructed as shown in (4),

$$C_{it} = \alpha C_{it-1} + \beta X_{it} + Z_{it} + \mu_i + \varepsilon_t \qquad (4)$$

Among them, i represents the cross-section unit of 30 provinces in China, and t represents the year; C_{it} is the explained variable, that is, the dual target of carbon emission reduction of province i in year t, that is, the total carbon emission or carbon emission intensity, C_{it-1} is the dual target of carbon emission reduction of province i in year t-1, d is the impact of the decline in carbon emissions in year t-1 on the decline in carbon emissions in year t; X_{it} is the core explanatory variable, namely the uncertainty of low-carbon governance environment; Z_{it} represents the control variable. μ_i represents the individual fixed effect of province i, and ε_t is the random disturbance term.

3.3.2. Panel Smooth Transition Model

As the uncertainty of the low-carbon governance environment changes, the degree or direction of its impact on the dual goals of carbon emission reduction may change. To describe the relationship between the uncertainty of a low-carbon governance environment and the dual goal of carbon emission reduction, the panel smooth transition (PSTR) model is used to study the uncertainty of a low-carbon governance environment as the conversion variable, as shown in the formula (5):

$$C_{it} = \delta_i + \pi X_{it} + \varpi X_{it} G(q, \phi, l) + e_{it} \qquad (5)$$

δ_i is the cross-section fixed effect, e_{it} is the random disturbance term, and the rest variables are the same as the dynamic panel model. G( ) is the transformation function, including the transformation variable q, the slope parameter ϕ , and the position parameter vector l, expressed as (6):

$$G\left(\varphi, l, q_{it}\right) = \frac{1}{1 + \exp\left(-\varphi \prod_{m=1}^{m}\left(q_{it} - l\right)\right)}, \varphi > 0 \qquad (6)$$

When m = 1, the PSTR model describes a smooth transition from one state to another; when m = 2, the transformation characteristics of the PSTR model are similar at both ends, but there are differences at the intermediate value. The value of G is between 0 and 1, and when G = 0, the model is in the low regime; when G = 1, the model is in the high regime.

4. Empirical analysis

4.1. Panel unit root test and panel cointegration test

To judge the stability of the data, the IPS test and Fisher test of the heterogeneous panel model are used to test the unit root of each variable to avoid pseudo-regression. The unit root test results of each data sequence are shown in table 3. Among them, variables X, CI, IN, and ES are I (1) processes, and the remaining variables are I (0) processes. The results show that all variables pass the unit root test.

Table 3. Panel unit root test results

Variable	IPS	P value	Fisher	P value	Variable	IPS	P value	Fisher	P value
X	4.1374	0.8164	1.3228	0.9621	△*X*	0.2754	0.0580	0.7034	0.0076
CT	1.5259	0.0092	0.1629	0.0076	△*ICT*	—	—	—	—
P	8.8804	0.0057	0.3757	0.0075	△*IP*	—	—	—	—
CI	0.5879	0.3259	0.2026	0.2703	△*ICI*	1.1508	0.0029	3.6158	0.0000
E	1.7709	0.0282	0.2481	0.9422	△*IE*	—	—	—	—
FDI	4.7627	0.0075	0.3176	0.0019	△*IFDI*	—	—	—	—
IN	0.9591	0.6572	0.1197	0.5402	△*IN*	0.7219	0.0077	0.2039	0.0058
ES	0.9964	0.8542	0.6223	0.8616	△*IES*	0.1844	0.0329	0.2516	0.0038

Note: If the original sequence of the variable is already a stationary process, the first-order difference sequence is no longer tested.

4.2. Linear Impact Analysis

We use the SYS-GMM estimation method to regress Equation (5), where the instrumental variable is the 1-2 order lag of the explained variable. The estimation results of the dynamic panel model are shown in Table 4. In the total carbon emission model and the carbon emission intensity model, the p values of AR (2) are greater than 0.05, and the p values of the Hansen test are greater than 0.1, indicating that both models accept the null hypothesis that there is no second-order sequence correlation in the residuals, so the instrumental variables selected by the model are valid.

In the total carbon emissions model, the estimated coefficient of low-carbon governance environmental uncertainty is 0.0898, significant at the 1 % level, indicating that the rise of low-carbon governance environmental uncertainty makes the total carbon emissions increase. Therefore, the uncertainty of the low-carbon governance environment is not conducive to the control of total carbon emissions but has a significantly positive impact on carbon emission intensity. For every unit increase in the uncertainty of a low-carbon governance environment, the decline in carbon emission intensity increases by 0.0931 units, which proves that the uncertainty of a low-carbon governance environment has a promoting effect on total carbon emissions and carbon emission intensity. China has actively promoted carbon emission reduction targets and made some achievements in carbon emission reduction. However, the research results also show that the rising uncertainty of the low-carbon governance environment has a certain negative impact on the dual goals of carbon emission reduction.

Table 4. Dynamic panel model estimation results

Variable	Model: Total Carbon Emissions	Model: Carbon Intensity
Lag	0.2628***(7.3204)	0.2634**(2.1425)
X	0.0898***(2.2440)	0.0931***(3.6241)
P	0.1527**(1.9464)	0.1066*(1.7353)
E	0.4332**(2.7635)	0.2059***(2.0218)
FDI	0.0926***(3.8635)	0.0891***(2.6254)
IN	0.1161**(1.6362)	0.1048**(1.7352)
ES	0.0999**(1.6248)	0.0059**(1.7335)
AR(2)	1.6257[0.0935]	0.2534[0.7341]
Hansen	0.0000[1.0000]	0.0000[1.0000]

*Note: *, **, and *** are significant at 10%, 5%, and 1% significance levels, respectively. The corresponding z values are in parentheses and the corresponding p values are in square brackets.*

4.3. Non-linear impact Analyze

In the dynamic panel model, the uncertainty of a low-carbon governance environment is used as an independent explanatory variable, and the uncertainty of a low-carbon governance environment is further transformed into a transformation variable. The PSTR model is used to study the different degrees of nonlinear effects of low-carbon governance uncertainty on the dual goals of carbon emission reduction.

4.3.1. Nonlinear test

First, check the nonlinear relationship between explanatory variables. r represents the number of conversion functions to determine whether the model has nonlinear effects. If the model has a nonlinear effect, further complete the ' residual nonlinear test ' to determine the number of transition functions. The results of the linear test and residual nonlinear test are shown in Table 2. The results show that there are significant differences between the explanatory variables and the explanatory variables of the total carbon emission model and the carbon emission intensity model, and the number of optimal conversions functions r* is 1. In the total carbon emission model and carbon emission intensity model, when m = 1, the absolute values of AIC and BIC are smaller, and the location parameters are within the sample interval. Therefore, it is determined that both models are two-region models, and the optimal form is expressed as m = l, r = l.

Table 5. Linear test and residual nonlinear test results

Panel A: Total Carbon Emissions						
	m=l			m=2		
	LM	LMF	LRT	LM	LMF	LRT
H_0 r =0 vs H_1 r=1	3.3319**	1.6219	14.1244**	7.0314***	2.6126***	13.8323***
H_0 r =1 vs H_1 r=2	3.7610	1.1941	12.2690	7.2781	1.5049	12.5710
AIC	-4.5224			-4.6137		
BIC	-4.1159			-4.1589		
Is c out?	NO			OUT		
Conclusion	m=1,r=l					
Panel B: Carbon Intensity						
	m=l			m=2		
	LM	LMF	LRT	LM	LMF	LRT
H_0 r =0 vs H_1 r=1	5.2851**	1.9161**	10.9541**	18.7639***	2.1806***	16.3433***
H_0 r =1 vs H_1 r=2	4.5631	0.8962	10.7837	16.6591	1.5648	14.5494
AIC	-6.3261			-6.3374		
BIC	-5.9456			-5.9346		
Is c out?	NO			OUT		
Conclusion	m=1,r=1					

4.3.2. PSTR model estimation results and analysis

Based on the nonlinear test, the nonlinear least squares estimation (NLS) method is used to estimate the smooth transition model of the panel. The estimation results are shown in Table 6.

Table 6 PSTR model estimation results

Item	**Variable**	**Total Carbon Emissions**	**Carbon Intensity**
Linear part	*X*	0.0942** (2.091)	0.1058** (1.0598)
Nonlinear part	*X*	0.1577** (2.091)	0.1440*** (4.6428)
Conversion slope	ϕ	13.1437	15.9026
Position parameters	*l*	4.5170	4.5948

In the total carbon emission model, the conversion slope is 13.1437, and the conversion position is X^* = 4.5170. In the carbon emission intensity model, the conversion slope is 15.9026, and the conversion position is X^* = 4.5948. The gap between the two is not large, indicating that the impact of uncertainty of low-carbon governance environment on total carbon emissions and carbon emission intensity is almost synchronized, and the impact on total carbon emissions is slightly faster than the impact on carbon emission intensity. When G = 0, the uncertainty of a low-carbon governance environment is low, in the low regime, the X estimated coefficient is 0.0942. At this time, the impact of a low-carbon governance environment on total carbon emissions is small, but the effect is more significant, through the 5% significance test; when G = 1, the uncertainty of low-carbon governance environment steps into the high regime interval, the estimated coefficient of X is still positive and passes the 1% significance test, its value is 0.0942+0.1577=0.2519; when 0<G< l, the uncertainty of the low-carbon governance environment is between the high-zone system and the low-zone system. At this time, the X-estimation coefficient smoothly transitions from 0.0942 to 0.2519. Therefore, the uncertainty of the low-carbon governance environment has a positive impact on the total carbon emissions, and as the uncertainty of the low-carbon governance environment increases, the positive impact on the total carbon emissions further increases. When the uncertainty of the low-carbon governance environment exceeds the threshold, the positive impact of low-carbon governance environment uncertainty on total carbon emissions will increase significantly.

In the test model of carbon emission intensity, when G = 0, the uncertainty of the low-carbon governance environment is in the low regime, and the X estimation coefficient is 0.1058. The impact of low-carbon governance uncertainty on carbon emission intensity is similar to that on total carbon emissions, but it does not pass the significance test at this time. When G=1, after the uncertainty of the low-carbon governance environment enters the high regime, the X estimation coefficient changes structurally, and the impact factor increases significantly from 0.1058 to 0.2498, with a significance level of 1%. When the low-carbon governance environment uncertainty is between the high regime and the low regime, the X estimate transitions smoothly between 0.1058 and 0.2498. This shows that with the increase of environmental uncertainty in low-carbon governance, its role in promoting carbon emission intensity gradually appears. Compared with the impact on total carbon emissions, the impact of increased uncertainty in a low-carbon governance environment on the increase of carbon emission intensity is relatively stable, but the overall carbon emission intensity continues to increase.

Compared with the dynamic panel model, the PSTR model divides the degree of environmental uncertainty in low-carbon governance. In the study of regions with different low-carbon governance environment uncertainties, the impact on total carbon emissions and carbon emission intensity is more targeted. The increase in environmental uncertainty in low-carbon governance has inconsistent effects on total carbon emissions and carbon emission intensity, and the difference is further amplified with the increase in uncertainty

4.3.3. Robustness test

To ensure the robustness of the research conclusions, the method of shortening the sample period is adopted. Specific treatment: to delete the first phase of sample data, the first two sample data, the first three sample data, and the rest using the dynamic panel regression model and PSTR model regression sample data. The analysis of the robustness measurement results shows that after shortening the sample period, the regression results are consistent with the above empirical results and have strong reliability.

4.4. Dimensional discussion

4.4.1 Linear test and residual nonlinear test

After verifying the impact of the overall uncertainty of the low-carbon governance environment on the dual objectives of carbon emission reduction, we further examine the impact of the uncertainty of each dimension of the low-carbon governance environment on the dual objectives of carbon emission reduction and specifically analyzes the impact of the uncertainty of low-carbon policy environment, low-carbon economic environment, low-carbon technological innovation environment, and carbon emission trading market on the dual objectives of carbon emission reduction. Linear test and residual nonlinear test results are shown in Table 7.

Table 7. Linear test and residual nonlinear test results

Panel A Total Carbon Emissions								
	Low Carbon Policy Environment		Low Carbon Economy Environment		Technological Innovation Environment		Market Environment	
	m=l	m=2	m=l	m=2	m=l	m=2	m=l	m=2
H_o r =0 vs H_1 r=1	3.3379*	4.0514***	3.3593*	4.2061***	2.6526***	3.8323***	2.0154***	1.3779*
H_o r =1 vs H_1 r=2	4.7120	2.7381	8.7103	2.7481	1.0549	2.7140	10.7841	2.7105
AIC	-4.5254	-4.6147	-4.5570	-7.3430	-1.8674	-1.8756	-3.3284	-5.0925
BIC	-4.1149	-4.1898	-5.3247	-8.6357	-2.1349	-2.2681	-3.2211	-3.8602
Is c out?	NO	OUT	NO	OUT	NO	OUT	NO	OUT
Conclusion	m=1,r=l		m=1,r=l		m=1,r=l		m=1,r=l	
Panel B Carbon Intensity								
	Low Carbon Policy Environment		Low Carbon Economy Environment		Technological Innovation Environment		Market Environment	
	m=l	m=2	m=l	m=2	m=l	m=2	m=l	m=2
H_o r =0 vs H_1 r=1	2.8551**	1.9361***	16.9411**	38.7659***	2.8036***	46.3533***	15.8541**	1.9641***
H_o r =1 vs H_1 r=2	4.6631	0.892	0.7827	13.6691	0.6438	14.4914	4.6231	1.8292
AIC	-6.3461	-6.8065	-3.2051	-3.8384	-3.8065	-3.9084	-6.3651	-6.5324
BIC	-5.9556	-6.0992	-3.4727	-3.6310	-5.0992	-5.7278	-5.9546	-6.1149
Is c out?	NO	OUT	NO	OUT	NO	OUT	NO	OUT
Conclusion	m=1,r=1		m=1,r=l		m=1,r=l		m=1,r=1	

It can be found that there are still significant differences between the explanatory variables and the explained variables, which are suitable for further investigation through the panel smoothing model. It can be determined that each subdimensional model is a two-region model, and the optimal form is expressed as $m = \text{I}\ r = \text{I}$.

4.4.2. PSTR model estimation

Based on verifying the nonlinear influence of the overall uncertainty of the low-carbon governance environment on the total carbon emission and carbon emission intensity, the smooth transition model of the panel under different dimensions of low-carbon governance environment uncertainty is further established for analysis. The estimation results are shown in Table 8.

Table 8. PSTR model estimation results

	Low Carbon Policy Environment		**Low Carbon Economy Environment**		**Technological Innovation Environment**		**Market Environment**	
	Model(1)	Model(2)	Model(1)	Model(2)	Model(1)	Model(2)	Model(1)	Model(2)
Linear part	-0.0238^{*} (-2.0916)	0.0342 (1.1059)	0.1028^{*} (2.1091)	0.0642 (1.0569)	0.0638 (2.091)	0.1042 (1.3659)	0.0638^{*} (2.4091)	0.0372 (1.0259)
Nonlinear part	-0.1579^{**} (-2.0591)	0.1863^{**} (4.6128)	0.0625^{**} (2.2091)	0.1640^{***} (4.6428)	0.1007^{**} (2.6091)	0.1953^{***} (4.3164)	0.1547^{**} (2.0951)	0.1427^{***} (4.2651)
Conversion slope	3.1384	5.3151	4.1623	5.2176	3.3127	2.3127	5.6981	6.3084
Position parameters	1.3152	1.0382	2.2318	2.1065	2.3856	2.6127	2.6857	2.6512

In the low-carbon policy environment uncertainty model, the conversion slope of the total carbon emission model is 3.1384, and the conversion position is X^{*} = 1.3152. The conversion slope of the carbon emission intensity model is 5.3151, and the conversion position is X^{*}=1.0382. The sensitivity of total carbon emissions and carbon emission intensity to the variable of low-carbon policy environmental uncertainty is relatively low. But when faced with the uncertainty of low-carbon policy environment, the total carbon emissions and carbon emission intensity change almost at the same time, in the opposite direction. In the total carbon emissions model, the estimated coefficient of X changes from -0.0238 to -0.1817. The uncertainty of the low-carbon policy environment can hurt the total carbon emissions. When the uncertainty of the low-carbon policy environment enters the high-zone system, the negative impact on the total carbon emissions will increase significantly. In the model of total carbon emissions, the estimated coefficient of X changes smoothly from -0.0238 to -0.1817, and the uncertainty of the low-carbon policy environment harms total carbon emissions. In the model of carbon emission intensity, the estimated coefficient of X changes smoothly from 0.0342 to 0.2205, and a low-carbon policy environment has a positive impact on carbon emission intensity.

In the low-carbon economic environment uncertainty model, the uncertainty of the low-carbon economic environment can lead to an increase in total carbon emissions and carbon emission intensity. In the carbon emission intensity model, the X estimation coefficient changes structurally, and the X estimation value is between 0.0642 and 0.2282. When the environmental uncertainty of low-carbon economy enters the high regime, the promoting effect on carbon emission intensity increases significantly. Financial instruments such as capital market, foreign exchange market and green finance contain certain financial risks. The capital and foreign exchange markets are currently unstable under the impact of the new coronavirus pandemic. In the short term, the uncertainty and risk of low-carbon economic environment have no negative impact on carbon emission reduction. However, in the long run, if the uncertainty of low-carbon economic environment enters the high regime, the liquidity demand of economic entities and capital markets will increase significantly, and the potential expansion of high energy-consuming industries, accompanied by the transfer of polluting industries and unreasonable medium and long-term interest rates, will have a negative impact on sustainable development and carbon emission reduction. In addition, rapid development of green finance accelerates the uncertainty of the economic environment, and capital should be further guided to rationally finance the green financial market to support the development of low-carbon economy. The environmental uncertainty of low-carbon economy has a weak driving force for carbon emission intensity and has a certain resistance to the goal of carbon emission intensity reduction.

In the low-carbon policy environment uncertainty model, the conversion slope of the total carbon emission model is 3.1384, and the conversion position is $X^* = 1.3152$. The conversion slope of the carbon emission intensity model is 5.3151, and the conversion position is X^*=1.0382. The sensitivity of total carbon emissions and carbon emission intensity to the uncertainty of the low-carbon policy environment is relatively low, but in the face of the uncertainty of the low-carbon policy environment, the total carbon emissions and carbon emission intensity change almost simultaneously, but in the opposite direction. In the total carbon emission model, the estimated coefficient of X changes from -0.0238 to -0.1817. The uncertainty of the low-carbon policy environment can hurt the total carbon emissions. When the uncertainty of the low-carbon policy environment enters the high-zone system, the negative impact on the total carbon emissions will increase significantly. In the model of total carbon emissions, the estimated coefficient of X changes smoothly from -0.0238 to -0.1817, and the uncertainty of the low-carbon policy environment harms total carbon emissions. In the model of carbon emission intensity, the estimated coefficient of X changes smoothly from 0.0342 to 0.2205, and a low-carbon policy environment has a positive impact on carbon emission intensity.

In the low-carbon economic environment uncertainty model, the uncertainty of the low-carbon economic environment can lead to an increase in total carbon emissions and carbon emission intensity. In the carbon emission intensity model, the X estimation coefficient changes structurally, and the X estimation value is between 0.0642 and 0.2282. When the environmental uncertainty of a low-carbon economy enters the high regime, the promoting effect on carbon emission intensity increases significantly. Financial instruments such as capital markets, foreign exchange markets, and green finance contain certain financial risks. The capital and foreign exchange markets are currently unstable under the impact of the new coronavirus pandemic. In the short term, the uncertainty and risk of a low-carbon economic environment has no negative impact on carbon emission reduction. However, in the long run, if the uncertainty of a low-carbon economic environment enters the high regime, the liquidity demand of economic entities and capital markets will increase significantly, and the potential expansion of high energy-consuming industries, accompanied by the transfer of polluting industries and unreasonable medium and long-term interest rates, will harm sustainable development and carbon emission reduction. In addition, the risk of green finance accelerates the uncertainty of the economic environment, and capital should be further guided to rationally finance the green financial market to support the development of the low-carbon economy. The environmental uncertainty of a low-carbon economy has a weak driving force for carbon emission intensity and has a certain resistance to the goal of carbon emission intensity reduction.

In the model of the impact of low-carbon technology innovation environmental uncertainty on total carbon emissions and carbon emission intensity, the X estimation coefficients have structural changes. The conversion slope of the total carbon emission model is 3.3127, and the conversion position is $X^{*}= 2.3856$. The conversion slope of the carbon emission intensity model is 2.3127, and the conversion position is $X^{*}= 2.6127$. Faced with the uncertainty of a low-carbon technology innovation environment, total carbon emissions and carbon emission intensity change alternately. In the total carbon emission model, the estimation coefficient of X changes smoothly from 0.0638 to 0.1007. The uncertainty of a low-carbon technological innovation environment can have a positive impact on total carbon emissions. With the increase of the uncertainty of the low-carbon technological innovation environment, the difficulty of achieving carbon emission reduction targets increases significantly. When technological innovation is impacted and faces the dilemma of technical mastery, the total amount of regional carbon emissions will rise rapidly, and the effect will increase cumulatively. In the carbon emission intensity model, the uncertainty of the innovation environment has a higher positive impact on carbon emissions. Regional carbon emission intensity will have a huge increase. This shows that the uncertainty of technological innovation will have a strong negative impact on regional carbon emission reduction targets, making the total carbon emissions and carbon emission intensity increase. Therefore, we should attach great importance to the innovation environment and guide the gradual advancement of carbon emission reduction targets through low-carbon technological innovation.

Finally, in the carbon emissions trading market environment uncertainty model, the PSTR model results show that in the low-carbon policy environment uncertainty model, the conversion slope of the total carbon emissions model is 5.6981, and the conversion position is $X^{*} = 2.6957$. The conversion slope of the carbon emission intensity model is 6.3084, and the conversion position is $X^{*} = 2.6512$. After entering the high regime, the$X$ estimation coefficient in the carbon emission intensity model changes structurally, and the X estimation value transits smoothly between 0.0372 and 0.1799. The reason may be that as the environmental uncertainty of the carbon trading market increases, its obstacles to the goal of reducing carbon emission intensity suddenly appear. At present, China has formed a trend of parallel regional and national carbon trading markets. The price of carbon emission rights has great volatility, and the liquidity of the carbon trading market is relatively lacking. The setting of the total quota and coverage of the carbon emission trading mechanism will directly affect the cost, capacity, and overall effect of the carbon emission trading market. Taking carbon emission rights as the carrier to restrict the carbon emissions of enterprises, in the changing environment of the carbon trading market, further exerting the carbon emission trading mechanism will lead the emission control enterprises, and make the best production and carbon emission selection according to the future production and cost plan and emission reduction cost plan, which is the collision between "traditional school" and "Porter hypothesis". Under the domestic demand channel, the realization of carbon emission reduction targets puts forward higher and more detailed requirements for the carbon trading market environment.

Conclusions

We discuss the uncertainty of China's low-carbon governance environment. Based on the existing research results, this paper constructs a new framework for analyzing the national low-carbon environmental governance system from four aspects: policy environment uncertainty, economic environment uncertainty, innovation environment uncertainty, and market environment uncertainty. Using this framework, the uncertainty of a low-carbon environmental governance system is measured and its impact on carbon emission reduction targets is analyzed. To establish a framework of low-carbon environmental governance including multiple subjects, and form an important way for China to achieve carbon emission reduction targets. At the level of influence mechanism, a low-carbon governance environment can affect China's dual goals of carbon emission reduction through four channels: policy environment, economic environment, technological environment, and market environment. Using the dynamic panel model and PSTR model, based on the panel data of low-carbon policy, economy, technology, and market development of 30 provinces in China, the empirical test results show that: (1) The uncertainty of low-carbon governance environment in China is not conducive to the realization of the goal of reducing total carbon emissions and carbon emission intensity, and under different regimes, the uncertainty of low-carbon governance environment in China has different effects on the dual goals of carbon emission reduction. When the uncertainty of the low-carbon governance environment is low and in the low-zone system, it has little impact on the total carbon emissions and carbon emission intensity. With the increase of the uncertainty of a low-carbon governance environment, its impact on the emission reduction target of total carbon emissions is very significant, and the promotion of carbon emission intensity gradually appears. Compared with the impact on total carbon emissions, the impact of increased uncertainty in a low-carbon governance environment on carbon emission intensity is relatively stable. (2) From the perspective of dimensions, the environmental uncertainty of China's low-carbon policy has a significant role in promoting the emission reduction target of total carbon emissions. We should further improve the formulation and implementation of a low-carbon policy to maximize its important role in carbon emission reduction targets. The uncertainty of each dimension has no significant impact on carbon emission intensity in the low-zone system. The reason is that China's carbon emission trading market is an emerging market, and its development is not as mature as the EU carbon market. The risk spillover and linkage between the financial market and the carbon market are not significant, which makes the impact of market environment uncertainty on carbon emission intensity not significant. (3) When the uncertainty of the sub-dimension of the low-carbon governance environment is high, other dimensions hurt carbon emission reduction targets except for the low-carbon policy environment.

Accordingly, the following policy recommendations are put forward: (1) From the overall environment of low-carbon governance to achieve multi-point force, from the emphasis on a single government policy to the joint investment of enterprises and other social market players, stabilize the expectations of carbon emission reduction targets and gradually fine-tune, improve the integrity and guidance of low-carbon policies, the stability of low-carbon economic development and the vitality of the carbon trading market, steadily promote the improvement of low-carbon governance environment, play a multi-dimensional synergistic effect of low-carbon governance environment, and accelerate the realization of carbon emission reduction targets. (2) Improve the formulation and implementation process of low-carbon policy. Formulating reasonable regional environmental regulation intensity according to the current situation of regional development to activate the endogenous power of energy conservation and emission reduction. Improve the completeness of regional environmental protection policies, increase the importance of policy implementation process and implementation effect, and solve the problem that local governments do not pay enough attention to carbon emission reduction caused by fiscal decentralization. Local governments should further improve the transparency of environmental information disclosure, and strengthen the attention of local environmental protection officials to low-carbon governance. (3) Improve the robustness of a low-carbon economic environment. With the improvement of regional foreign trade openness, the uncertainty of a low-carbon governance environment inevitably falls into the high-value range, and carbon emission reduction is facing more severe challenges. Accelerate the decoupling speed of regional economic development and carbon emissions. By maintaining the stability of the regional capital market and the completeness of green finance development, improving the inhibition of green finance on investment and financing of high-emission enterprises, and forming an incentive mechanism to promote a low-carbon economy. (4) Construction of a 'low-carbon technology industry cooperation network', to achieve high and stable low-carbon technology cooperation and innovation efficiency, to provide information for technology market cooperation. Improve the international competitive advantage and status of local enterprises, break the mid-end technology lock-in and improve the common technology mastery of low-carbon development. For high energy-consuming industries, as soon as possible to improve the speed of technological change, to promote collaboration between different innovation entities, and to achieve risk sharing and complementary benefits. Through complex technological innovation and frontier technological innovation, we constantly accumulate and enhance emission reduction capabilities and develop the possibility of emission reduction. (5) Promote the development of a regional low-carbon trading mechanism and implement it in stages to maintain its stability. Improve the construction capacity of regional energy and environmental exchanges to support the construction of carbon trading markets and maximize the use of national market resource advantages. In the stage of the rapid development of the national carbon emission trading market, we should improve the activity of the regional carbon trading market, accelerate the construction of the emission information management platform and improve compatibility with the national carbon emission trading market to achieve market compatibility. By using, absorbing, and integrating external scientific and technological resources, based on carbon emission reduction, we can achieve the established emission reduction targets.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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