중국 녹색금융이 탄소 배출에 미치는 영향
– 녹색혁신을 매개변수로 –

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The Influence of Green Finance on Carbon Emissions in China - Green technology innovation as a parameter -

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요 약 엔트로피 방법을 사용하여 2012년부터 2022년까지 중국 하남성 18개 시의 녹색신용, 녹색증권, 녹색투자, 녹색보험 등의 4개 지표를 측정하였다. 첫째, 표준화된 지표와 측정된 지표에 가중치에 따라 우리에게 필요한 녹색금융 발전지표를 산출하였다. 둘째, 녹색금융의 발전과 탄소배출량 수준에 관한 동태패널모형을 구축하고, 녹색금융이 탄소배출에 미치는 영향의 경로를 실증적으로 분석하였다. 연구결과, 녹색금융은 탄소배출에 직접적으로 영향을 줄 뿐만 아니라, 녹색혁신을 통해 간접적으로 이산화탄소 배출에 영향을 미치는 것으로 나타났다. 연구과정에서 녹색금융과 탄소배출의 전반적인 관련성을 분석하고 탄소배출에 대한 녹색금융의 구체적인 역할 메커니즘을 탐구했다. 녹색금융과 탄소배출의 전반적인 관련성을 분석하고 탄소배출에 대한 녹색금융의 구체적인 역할 메커니즘을 연구하였다.

주제어 : 녹색금융, 엔트로피방식, 탄소배출량, 녹색혁신, 녹색금융 발전지표

Abstract The entropy method is employed to measure the four indicators of green credit, green securities, green investment, and green insurance of 18 prefecture-level cities in Henan Province, China from 2012 to 2022. Firstly, based on the standardized indicators and the measured indicator weights, the green finance development indicators we require are obtained. Secondly, a dynamic panel model concerning the development of green finance and the level of carbon emissions is constructed, and the influence path of green finance on carbon emissions is empirically analyzed. The conclusion puts forward that: Firstly, green finance not only directly affects carbon emissions. Secondly, it also indirectly acts on carbon dioxide emissions through green innovation. The level of low-carbon economic transformation in Henan Province, China shows a continuous improvement trend. During the analysis process, an overall correlation analysis of green finance and carbon emissions is carried out, and the specific mechanism of green finance on carbon emissions is explored.

Key Words : Green Finance, Entropy Method, Carbon Emissions, Green Innovation, Green Finance Development Indicators

1. Introduction

The environmental pollution and climate disasters caused by industrial civilization have compelled the global community to reevaluate the relationship between humanity and nature, and sustainable development has gradually emerged as a global consensus and common goal. The transformation from industrial civilization to ecological civilization is regarded as a crucial means to address the contradiction between humanity and nature and achieve harmonious coexistence[1]. In 1992, the United Nations issued the first global climate legal document – the United Nations Framework Convention on Climate Change. Subsequently, the Kyoto Protocol, adopted in 1997, further stipulated that developed countries should assume the priority responsibility for emission reduction. In 2015, the Paris Agreement was passed and received support from the majority of countries worldwide. Its emission reduction targets are more stringent and binding than those of the Kyoto Protocol. This indicates that green and low-carbon development has become the core consensus globally.
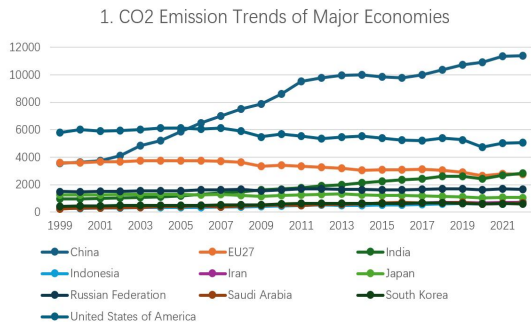

Figure 1. Co2 emissions Trends of Major Economies

As depicted in Figure 1. The carbon dioxide emissions in China have increased sharply, significantly exceeding the emission levels of other major economies worldwide. According to the data from the BP Statistical Review of World Energy, the growth rate of China's energy consumption reached 2.1% in 2020, raising China's share in the global total carbon emissions to 31%. Consequently, China is confronted with a severe challenge in international emission reduction and is in an unfavorable position.

Low-carbon development is an organic integration of "low carbon" and "development", and constitutes a component of sustainable development. It is a development approach that guarantees the attainment of higher resource productivity and enables people to share superior living standards and quality of life. On one hand, low-carbon development seeks to reduce carbon dioxide emissions; on the other hand, it optimizes resource allocation and averts resource misuse by enhancing institutional mechanisms, thereby achieving economic and social development with lower losses and greater efficiency. Both low-carbon development and the low-carbon economy are dedicated to shaping environmentally and climate-friendly development patterns. Low-carbon development emphasizes the unity of politics, economy, society, and ecology in low-carbon advancement, while the low-carbon economy focuses on the low-carbonization of all aspects of economic production activities. Low-carbon development is the ultimate objective of the low-carbon economy, and the low-carbon economy is the intrinsic nature of low-carbon development. Hence, it is highly essential to investigate how to utilize green finance to reduce carbon emissions while facilitating economic development.

Based on the previous research results, this paper investigates the mechanism of green finance in urban carbon emissions. The research innovations are as follows: The existing literature merely focuses on the examination of the relationship between green finance and carbon emissions, and few have delved into the channels through which the development of green finance affects the level of carbon emissions. On the basis of theoretical analysis, an empirical study is conducted using the method of the mediating effect model. It is found that the mechanism path of the role of green finance in urban carbon emissions also encompasses green innovation.

2. Literature Review

The independent variable, green finance, has received multi-dimensional interpretations from international organizations, governments, and the academic community since the 1980s. Salazar[2] proposed that through innovation, the financial and environmental sectors could achieve coordinated development. Cowan's[3] study indicated that green finance is an effective approach to integrating green development with financial theory. Moreover, Labatt and White[4] emphasized that the market mechanism is the core of green finance, which not only enhances environmental quality but also reduces environmental risks. Yang[5] classified the development process of green finance in China into three stages: the embryonic stage, the development stage, and the rapid development stage.

Despite the slight differences in the expressions of the above definitions of green finance, their cores all focus on promoting sustainable development of the economy and society. Additionally, green finance is closely related to concepts such as sustainable finance, environmental finance, climate finance, transition finance, and carbon finance. To define the relationships among these concepts more clearly, referring to the viewpoint of Noh[6], starting from the ultimate goals, their relationships can be presented in Table 1 for a

better understanding of the connotation of green finance. Table 2 presents six terms closely related to green finance to facilitate the comparison of conceptual similarities and differences between green finance and other terms.

The Stern Report published in 2006 indicated that the low-carbon economy is a new economic form encompassing low-carbon industries and low-carbon technologies. Scholar Zhang[7] defined the low-carbon economy as an economic model based on low energy consumption, low emissions, and low pollution. Lin and Sun[8] defined the low-carbon economy as an economic growth mode that considers both development and sustainability. In general, the low-carbon economy is a new economic form with staged characteristics of development[9]. To achieve a low-carbon economy, it is necessary to conform to the principles of economic rationality and sustainability. Whether through policy regulation or incentive measures, the sustainability and economic costs involved should be considered[10]. Low-carbon development is an organic combination of "low-carbon" and "development" and is a part of sustainable development. Low-carbon development is a development path that guarantees higher resource productivity and enables people to share better living standards and quality of life. Shu and Jiang[11] pointed

Table 1: Summary of Green Finance Policies Enacted by China in Recent Years

Time	Name	Key Points
2012	《Guiding Opinions on Accelerating the Development of Green Finance》	Propose the goals and directions for the development of green finance
2012	《Guidelines for Green Credit》	Facilitate the development of green credit by banking institutions
2015	《Guiding Opinions on Promoting the Development of Green Finance》	Clarify the development direction of green finance
2015	《Guidelines for the Issuance of Green Bonds》	Specify the applicable scope and key support areas of green bonds
2016	《Guiding Opinions on Constructing a Green Financial System》	Establish a relatively complete regulatory system of green finance policies
2017	《Implementation Plan for the Evaluation of Green Banks in the Chinese Banking Industry (Trial)》	Carry out the work of green credit in banking institutions and conduct green bank evaluations
2018	《Notice on Conducting the Performance Evaluation of Green Credit of Banking Deposit-taking Financial Institutions》	Formulate a new performance evaluation method for green credit, which is divided into qualitative evaluation and quantitative evaluation
2021	《Evaluation Scheme for Green Finance of Banking Financial Institutions》	Establish quantitative and qualitative evaluation indicators for green finance
2022	《Green Finance Guidelines for the Banking and Insurance Industry》	Promote the development of green finance in the banking and insurance sectors
2022	《Principles of Green Bonds in China》	Mark the official establishment of a unified green bond standard

out that the mediating variable of green technologyinnovation cannot be regarded unilaterally as a breakthrough in energy conservation and environmental protection technology, nor can it be simply seen as an economic act. It is a process in which energy conservation and environmental protection science and technology and the green economy gradually move towards integrated development. Moreover, Yu et al.[12] hold that green technology innovation can not only enhance the technological level of enterprises and significantly boost the competitiveness of energy conservation and environmental protection enterprises in the market, but also the benefits generated by innovative activities are conducive to the growth and expansion of energy conservation and environmental protection enterprises.

research adopts the theoretical research method, comprehensively collating and analyzing the research achievements and development overview of predecessors, summarizing its related theories and research status, with the aim of comprehensively grasping the relevant research theories on the impact of green finance on urban carbon emissions in recent years and laying a solid theoretical foundation for this study. Empirical analysis method: Regression analysis of the carbon emission level is conducted based on the green finance indicators obtained by the entropy method. The dynamic panel model is used to examine the effect of green finance development on carbon dioxide emissions, and the mediating effect model is employed to explore the impact of green finance on carbon emission reduction through green innovation,

Table 2: The objectives of key concepts in green finance terminology

Terminology	Definition	Time of Proposal and Key Objectives
Environmental Finance	The aim is to employ diversified financial tools for environmental protection, environmental governance, and biodiversity conservation.	In 1997, scholars put forward the concept, with the emphasis on supporting environmental protection and environmental governance activities.
Ecological Finance	The aim is to support ecologically friendly and rational financial investment and financing activities.	In 1974, German financial institutions proposed it, with the key focus on the area of ecological balance and the value of ecological products.
Climate Finance	The aim is to respond to climate change and promote low-carbon development, where financial activities are designed to control greenhouse gas emissions and enhance the capacity for climate adaptation.	In 1992, it drew the attention of the United Nations Organization, with the main focus on controlling CO_2 emissions and supporting climate mitigation and adaptation activities.
Carbon Finance	The aim is to carry out climate investment and financing activities for reducing greenhouse gas emissions and increasing carbon sink capacity.	In 1997, it garnered the attention of the United Nations Organization, with the emphasis on reducing CO emissions and serving the carbon market.
Transition Finance	The aim is to provide financial support for the transformation of high-carbon and energy-intensive industries through financial activities.	In 2018, it received the concern of European countries, with the focus on the transformation and development of high-carbon industries and energy-intensive industries.
Sustainable Finance	The aim is to achieve long-term effective operation and stable development of the economy and finance, adjust the financial development system and mechanism, realize the rational and effective allocation of financial resources, and enhance financial efficiency.	After 1992, it gained the attention of relevant United Nations organizations, with the key point centering around conducting financial support activities related to the environmental and climate goals in the Sustainable Development Goals (SDGs).
Sustainable Financing	Financial activities with the aim of supporting environmental improvement, addressing climate change, and promoting efficient and resource-conserving utilization of resources.	In 1995, scholars proposed it. After 2015, it was vigorously developed in China, with the emphasis on environmental governance, reducing carbon emissions, and enhancing resource utilization efficiency.

3. Research Methodology

The research mainly employs theoretical research methods and empirical analysis methods. Theoretical

thereby providing scientifically reasonable suggestions for carbon emission reduction.

Data Source: This paper conducts an analysis based on the relevant data of 18 prefecture-level cities in

Henan Province, China, from 2012 to 2022. The data are sourced from the Emissions Database for Global Atmospheric Research released by the Joint Research Centre(JRC) of the European Union, the global carbon atlas database, the National Bureau of Statistics of China, the China Carbon Accounting Database(CEADs), the China Research Data Service Platform (CNRDS), the CSMAR database, the WIND database, the China Statistical Yearbook, the China Fixed Asset Investment Statistical Yearbook, the China Fixed Asset Investment Statistical Annual Report, the Statistical Yearbook of Henan Province, the Statistical Yearbook of Urban and Rural Construction in China, the Statistical Yearbook of Insurance in China, and the statistical yearbooks of various prefecture-level cities in Henan Province.

Constructing a green financial system is a complex and systematic undertaking. Wang[13] contends that the establishment of a green financial system entails three phases: the search period, the transitional period, and the maturity period. Zeng[14], based on personal experience, assigned corresponding weights to diverse green financial indicators and derived the comprehensive score of green finance by multiplying the indicator values with their weights. Yuan[15] likewise adopted the subjective scoring method and, relying on the practical experience of industry experts, determined the weights of each green finance indicator. Building upon Zeng Xuewen's research, Dong and Fu[16], on the basis of statistical data, calculated the weights of each indicator via the entropy method and ultimately measured the score of China's green finance from 2008 to 2016. Xia[17] integrated these research outcomes and innovatively combined the entropy method with the Analytic Hierarchy Process (AHP) to determine the comprehensive weights of each indicator.

The following is the specific procedure of the Entropy Value Method: Firstly, each indicator is standardized. The standardization process for positive indicators is presented in the first formula, while that for negative indicators is shown in the second formula.

$$X_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)}$$

$$X_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)}$$

"J" is a region, "I" is a year, where "$\max(X_j)$"represents the maximum value of all years in region "J", and "$\min(X_j)$"represents the minimum value of all years in region "J", "X_{ij}" is the numerical value of the year "I" and region "J", and finally, by standardizing, the financial index for each region is confirmed.

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$$

Compute the proportion "P_{ij}" of the jth region in the ith year. According to the proportions "P_{ij}" of each indicator, calculate the entropy value "E_j" of each indicator:

$$E_j = -k \sum_{i=1}^{m} P_{ij} * \ln(P_{ij})$$

Table 3 Index System of Green Finance Development Index

Objective Indicators	First-level Indicators	Second-level Indicators	Indicator Implications
Index of Green Finance Development	Green Credit	Proportion of Interest Expenditure in High-Energy Industry	Interest of High Energy-Consuming Industrial Industry/Interest of Industrial Industry
	Green Securities	Proportion of Market Capitalization of Environmental Protection Enterprises	Market Capitalization of Environmental Protection Enterprises/Total Market Capitalization of Listed Enterprises
	Green Investment	Proportion of Investment in Environmental Pollution	Investment in Environmental Pollution/Total GDP
	Green Insurance	Proportion of Agricultural Insurance	Income of Agricultural Insurance/Agricultural Gross Output Value

Herein, the constant , aiming to standardize the entropy value "E_j", with $0 \leq E_j \leq 1$.

The information utility value "d_j", which reflects the information quantity of the "j"th indicator, has the following formula:

$$d_j = 1 - E_j$$

The weights "w_j" of each indicator are computed based on the information utility value "d_j":

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

Utilizing the calculated weights "W_j", the comprehensive score "S_i" for each evaluated object is determined.

$$S_i = \sum_{j=1}^{n} (w_i * X_{ij})$$

Using standardized indicators "w_j" and measured indicator weights "S_i", we calculate the green finance development indicator "" that we need.

4. Research result

To investigate the influence level of green finance on urban carbon emissions, the 18 prefecture-level cities all originated from one province. Considering the immediacy of policies. By referring to the research approaches of Gao and Xue[19], and making improvements based on the research object, the following dynamic panel model regarding the impact of green finance on carbon emissions was established:

$$C_{it} = \alpha_0 + \alpha_1 GF_{it} + \sum \alpha_2 Z_{jit} + \varepsilon_{it}$$

In the model equation, "C_{it}" denotes the carbon emission level of city "i" in year "t", "GF_{it}" indicates the development level of green finance, which is the green finance indicator measured by the entropy method in Table 3. "$\sum \alpha_2 Z_{jit}$" represents the collection of control variables influencing the carbon

Table 4 Definitions of Each Variable

Variable properties	Variable Designations	Notation	Variable Definitions
Explained variable	Carbon Emission Level	C	Carbon emissions / GDP
Explanatory variable	Development Level of Green Finance	GF	Entropy Measurement Method in Chapter 3
Intermediary variable	Green Technological Innovation	GI	Number of green inventions / Total population at the end of the year
Control variable	Urbanization Level	UR	Urban resident population / Total resident population of the city
	Educational Expenditure	SE	Ln (Scientific expenditures + Educational expenditures)
	Investment in Fixed Assets	FI	Ln (Fixed asset investment / Population at the end of the year)
	Government Fiscal Expenditure	GOV	Government fiscal expenditure / GDP

The main variable of this paper is green finance. Referring to the previous studies of Guo and Peng[18], the explanatory variable of green finance is categorized into four dimensions: green credit, green securities, green investment, and green insurance, and the data is measured by the entropy method. As presented in Table 3, the indicators and their implications in the four dimensions are expounded.

emission level. α_0、α_1、α_2 respectively correspond to the regression coefficients of the core explanatory variables and the collection of control variables, and "ε_{it}" represents the random disturbance term. Table 4 offers the explanations of the variables required.

Through the established panel model, the two variables of green finance indicators and carbon dioxide emissions were regressed along with other control variables to investigate the dynamic influence of green

Table 5 Results of Linear Regression Analysis (n = 11)

	Unstandardized Coefficient		Standardized Coefficient	t	p	Collinearity Diagnostics	
	B	Standard Error	Beta			VIF	Tolerance
Constant	54713.119	3293.752	–	16.611	0.000**	–	–
GF	-50487.773	4249.358	-0.970	-11.881	0.000**	1.000	1.000
R²				0.940			
Adjusted R²				0.933			
F				F (1,9)=141.165,p=0.000			
D-W Value				2.219			

Note: Dependent Variable = Carbon Emission Level (C)

* p<0.05 ** p<0.01

finance on carbon dioxide emissions in 18 prefecture-level cities of Henan Province from 2012 to 2022. The regression results of this model are reported in Table 5.

significance level of 1%, the influence coefficient of the core variable, green finance, is negative, suggesting that the advancement of green finance is conducive to reducing carbon dioxide emissions.

Table 6 Results of Linear Regression Analysis (n = 11)

	Unstandardized Coefficient		Standardized Coefficient	t	p	Collinearity Diagnostics	
	B	Standard Error	Beta			VIF	Tolerance
Constant	-0.912	0.187	–	-4.887	0.001**	–	–
GF	1.492	0.241	0.900	6.194	0.000**	1.000	1.000
R²				0.810			
Adjusted R²				0.789			
F				F (1,9)=38.368,p=0.000			
D-W Value				1.924			

Note: Dependent variable = Green Financial Innovation

* p<0.05 ** p<0.01

It can be learned from Table 5 that the regression coefficient value is -50487.773 (t = -11.881, p < 0.001), which implies that the financial index has a significantly negative influence on the carbon emission level. On the whole, green finance presents a negative correlation with carbon dioxide emissions. At a

This paper utilizes the traditional three-step approach of mediating effect to examine the functional mechanism on green innovation. With reference to the research framework of Barrro and Kenny[20]. The modification employed the mediating effect analysis method proposed by Baron and Kenny. the mediating

Table 7 Results of Mediation Analysis (n = 11)

	C					GI					C				
	B	Standard Error	t	p	β	B	Standard Error	t	p	β	B	Standard Error	t	p	β
Constant	54713.119**	3293.752	16.611	0.000	–	-0.912**	0.187	-4.887	0.001	–	54149.203**	6673.277	8.114	0.000	–
GF	-50487.773**	4249.358	-11.881	0.000	-0.970	1.492**	0.241	6.194	0.000	0.900	-49565.574**	10333.699	-4.796	0.001	-0.952
GI											-617.993	6232.418	-0.099	0.923	-0.020
R²	0.940					0.810					0.940				
Adjusted R²	0.933					0.789					0.925				
F	F (1,9)=141.165,p=0.000					F (1,9)=38.368,p=0.000					F (2,8)=62.822,p=0.000				

* p<0.05 ** p<0.01

effect test is constructed. The specific steps are as follows: First, taking green technological innovation as the explained variable and the development level of green finance as the explanatory variable for regression. Second, incorporating the development level of green finance as the explanatory variable and green innovation as the mediating variable into the model for regression.

It can be known from Table 6 that the regression coefficient value of the financial index is 1.492 (t = 6.194, p < 0.001), which implies that the financial index has a significantly positive influence on green financial innovation. The summary analysis reveals that all financial indices have a significantly positive impact on green financial innovation.

It can be learned from Table 7 that green innovation exerts a certain mediating effect on carbon emissions. According to the surveyed literature and empirical analysis, this paper contends that green innovation plays a certain mediating role in the process where green finance affects urban carbon emissions. Green finance is capable of providing financial support for environmental protection and technological innovation, and facilitating investment in low-carbon technologies. With the passage of time, the achievements of green innovation will be gradually transformed into green productivity, which will reduce reliance on high-carbon emission energy sources and lower carbon dioxide emissions.

5. Conclusion and policy suggestions

From the perspective of the current economic development stage in China, joint development of green finance and transition finance should be emphasized. The "White Paper on 'Providing Financial Support for Trustworthy Low-Carbon Transition Activities'" released by the Climate Bonds Initiative in 2020 has explicitly proposed that transition finance can contribute to "climate mitigation transition" and is applicable to promoting the achievement of the "dual

carbon" goal. China's economic development is confronted with multiple pressures such as contracting demand, supply shocks, and resource constraints. It is undergoing a long-term transformation period of the economic development mode. Continuously elevating the level of low-carbon economic transition is not only a necessary response to the concepts of innovation, coordination, and green development among the Five Development Concepts, but also an important direction and path for promoting sustainable regional economic development [21]。

This paper conducts a dynamic analysis of the development level of green finance and the level of carbon emissions from 2012 to 2022. It is found that the level of green finance in Henan Province has been rising steadily year by year, while the level of carbon emissions has shown an overall downward trend. The level of economic low-carbon transformation in Henan Province of China presents a continuously improving situation. However, on the whole, the average economic low-carbon transformation performance of prefectural-level cities is relatively low, and a fundamental improvement has not yet been achieved. The issuance of green finance policies has a positive influence on the economic low-carbon transformation of prefectural-level cities. This conclusion provides a green finance solution for China to achieve economic low-carbon transformation from the financial perspective. At the same time, it is discovered that green innovation plays a certain mediating role in the process of green finance influencing urban carbon emissions, but this effect requires time to manifest.

To promote the all-round development of green finance, it is necessary to formulate appropriate strategies and policies for the low-carbon transformation of the economy. Through the rational allocation of funds, a powerful supporting force can be provided for the development of the low-carbon economy. All regions should closely integrate these guidelines, further improve and deepen the implementation plans of green finance, ensure a

positive financial role in economic transformation, improve the green finance policy system, and optimize the synergy mechanism among policies. At the central policy level, further green finance development plans that are consistent with the goals of carbon peak and carbon neutrality should be formulated, and a green finance policy system and supporting implementation plans closely related to pollution reduction and carbon reduction should be explicitly proposed.

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