Effect of Green Finance on Industrial Carbon Emissions in China ——Empirical Analysis Based on Provincial Panel Data

Yingying Zhou[1*], Zhuoran Zhou[1], Youxin Zhang[1], Yilin Chang[2]

[1]China University of Mining and Technolog, School of Economics and Management, 221116 Xuzhou, China
[2]Zhongnan University of Economics and Law, Wenlan School of Business, 430073 Wuhan, China

Abstract. Based on the Environmental Kuznets Curve (EKC), this paper empirically analyzes the impact of green finance development on industrial carbon emissions in China by using the panel data of Chinese mainland province. It is found that the development of green finance has significantly suppressed the industrial carbon emissions in China. Heterogeneity test shows that the inhibition effect on carbon emission in central China is the most obvious, and the inhibition effect on carbon emission in eastern and western regions decreases in turn. Technological progress significantly inhibits carbon emissions, especially in central China, followed by the western region and finally the eastern region. It is suggested to improve the green and low-carbon financing system, support the optimization of energy consumption structure and guide substantive technological progress, so as to promote the realization of carbon emission reduction targets.

1 Introduction

With the deepening of industrialization, a large number of greenhouse gases, mainly carbon dioxide, are emitted, and it is an indisputable fact that the global temperature is rising. Green finance guides all economic entities to pay attention to the natural ecological balance through their own activities, which is a financial service for improving the environment, saving resources and coping with climate change, and helps to achieve the goal of "double carbon". Since the issuance of "Guiding Opinions on Building a Green Financial System", local governments have made concerted efforts to jointly build a green financial framework. It is widely believed that combining green finance with environmental policies can effectively control the level of environmental pollution, promote the greening and sustainability of economic development. On one hand, policies related to green finance guide financial institutions to provide loans to environmentally friendly businesses, thereby promoting the development of the green economy and reducing carbon emissions. On the other hand, green finance can stimulate innovation in green technologies, improve energy equipment at the provincial level, and reduce carbon emissions.With so many inputs and outputs, does the development of green finance actively and effectively curb carbon emissions? Based on the data of 30 provinces in mainland China from 2005 to 2020, this paper explores the actual impact of green financial development and technological progress on industrial carbon emissions in China by building a panel data regression model.

2 Literature review

At present, there are many research results on the influencing factors of carbon emissions, including economic growth, industrial structure and financial development. Among them, scholars from all walks of life hold different opinions on financial development.

Green finance and carbon emission reduction are the relationship between ways and purposes, so the impact of green finance development on carbon emission reduction has become a highly valued issue in economics. Bai et al. (2022), Liu Feng et al. (2022) and Li Yunyan et al. (2023) believe that there are regional differences in the role of green finance in carbon emissions. Bai et al. (2022) think that green finance has become an important means to reduce carbon emissions in the eastern region, and the impact of green finance on carbon emissions in the central region is inverted U-shaped, while the driving force of green finance on carbon emissions reduction in the western region is weak ([1]).

Liu Feng et al. (2022) think that green finance has the most obvious effect on carbon emissions in the central region, but not in the eastern region. Li Yunyan and Zhang Shuo (2023) think that economic development has a positive regulatory effect on the carbon reduction effect of green finance, and the carbon reduction effect of green finance in developed regions is stronger than that in underdeveloped regions.Yasir et al. (2023) utilizing the Delphi and fuzzy Analytical Hierarchy Process(FAHP) method specify that green finance development is a very crucial strategy to minimize carbon emissions. Muhammad

* Corresponding author: zhouyingying@cumt.edu.cn

Umar et al. (2023) pointed out that focusing on green finance and green innovation can help achieve sustainable environmental goals ([2]). Md Al Mamun et al. (2023) used a large sample of 46 countries to verify that green finance significantly reduces carbon emissions in the short and long term ([3]).

Mao Yanjun, Qu Yingbo (2023) and Chen X et al. (2021) think that there is spatial spillover effect in the development of green finance. Mao Yanjun and Qu Yingbo (2023) pointed out that the development of local green credit can not only significantly inhibit local carbon dioxide emissions, but also have a significant negative impact on neighboring carbon dioxide emissions through spatial spillover effect. Chen X et al. (2021) proposed that the development of green finance can not only reduce the carbon emissions in this region, but also restrain the carbon emissions in neighboring regions.

To sum up, it is of theoretical and practical significance to study the relationship between green finance development and carbon emission level.

3 Model construction, data source and variable measurement

3.1. Model Building

Grossman and Krueger first pointed out the "inverted U" relationship between pollutants (sulfur dioxide and dust) and per capita income level. Panayotou (1993) thought that the relationship between economic development and environmental pollution showed an "inverted U" curve, and named it Environmental Kuznets Curve (EKC). Based on the analysis framework of environmental Kuznets curve (EKC) and referring to the practice of scholars such as Liu Feng and Huang Ping (2022), this paper sets the following model, simplifies the logarithmic quadratic function, eliminates the strong fluctuation of data, and tests the impact of green finance on carbon emissions. Equation 1 is the model constructed in this study.

$$\ln co_{2it} = c + \alpha_1 \ln gf_{it} + \alpha_2 \ln gdp_{it} + \alpha_3 \ln rd_{it} + \alpha_4 \sum Z_{it} + Year_t + \mathrm{Re}\,gion_i + \varepsilon_1 \quad (1)$$

In Equation 1, it represents the carbon emission intensity of the region in the first year and represents the development level of green finance. It means the level of economic development, which means that the R&D expenditure in the year accounts for the local GDP in that year, and it is a set of control variables that affect the explained variables. It is a constant term and a random disturbance term. In addition, year ($year_t$) fixed effect and city ($Region_i$) fixed effect are added to the model to control the influence of unobservable factors in the year and city. The control variables mainly include urbanization level (city), environmental regulation (reg) and industrial structure (ind), proportion of local fiscal expenditure (cz) and proportion of foreign investment (FDI).

3.2. Data sources and variable measurement

Carbon emission data comes from China Carbon Accounting Database (CEADs), and other data come from China National Bureau of Statistics, Securities Times, Times Finance, China Insurance Yearbook, and statistical yearbooks of 32 statistical bureaus such as Beijing Municipal Bureau of Statistics, Tianjin Municipal Bureau of Statistics, Hebei Provincial Bureau of Statistics and Shanxi Provincial Bureau of Statistics. The implementation effect of national policies is often influenced by the strict constraints and effective implementation of provinces, so this paper uses the samples of 30 provinces in Chinese mainland (Tibet Autonomous Region, Hong Kong Special Administrative Region, Macao Special Administrative Region and Taiwan Province are not selected for research). This paper selects the data of 30 provinces in China from 2005 to 2020 for empirical test.

The development level of different provinces is different, so the comparability of directly comparing carbon dioxide emissions is relatively low. Therefore, this article characterizes carbon emissions through carbon emission intensity (carbon emission efficiency), and measures the proportion of carbon dioxide emissions in each province to per capita GDP in the region. It represents the carbon dioxide (CO_2) released per unit of GDP per capita produced, with a unit of 100000 tons per yuan. The Green Finance Index (gf) considers data availability and constructs measurement indicators from four dimensions: green credit, green insurance, green investment, and government support for green industries. The urbanization level (city) is measured using the proportion of urban population in each province to the total urban population; The level of economic development is characterized by provincial per capita GDP unit: 10000 yuan (gdp); The environmental regulation variable (reg) is characterized by industrial sulfur dioxide emissions at the provincial level. The industrial structure (ind) uses the proportion of the secondary industry at the provincial level to GDP. R&D expenses (rd) are represented by the proportion of provincial-level R&D expenses to local GDP for the current year. The proportion of local fiscal expenditure (cz) is represented by the proportion of provincial level fiscal expenditure to local GDP in the current year. The proportion of foreign investment (FDI) is measured by the ratio of the total output value of foreign-invested industrial enterprises to the total industrial output value of the city. Table 1 is a statistical description of each variable.

Table 1. Statistical description of variables

variable	Variable name	average number	Standard deviation	minimum value	maximum
CO_2	*Carbon emission (carbon intensity)*	*1.1072*	*0.8224*	*0.0700*	*4.5348*
gf	*Development level of green finance*	*0.1607*	*0.1031*	*0.0441*	*0.8390*
city	*Urbanization level*	*0.5516*	*0.1401*	*0.2687*	*0.8960*

gdp	***Level of economic development***	***4.4429***	***2.8224***	***0.5052***	***16.4890***
FDI	***Proportion of foreign investment***	***0.0217***	***0.0198***	***0.0001***	***0.1210***
reg	***Environmental regulation***	***56.8539***	***45.2342***	***0.1800***	***200.2000***
ind	***industrial structure***	***0.4319***	***0.0770***	***0.2862***	***0.7315***
rd	***R&D expenses***	***0.0147***	***0.0111***	***0.0018***	***0.0644***
cz	***Proportion of local fiscal expenditure***	***0.2253***	***0.0995***	***0.0792***	***0.6430***

4 Empirical analysis

Import the data into STATA, log the data with gen program, perform regression fitting on the log data, and control the time effect of fixed effect. Table 2 shows the benchmark regression results of the effect of green finance on carbon emission reduction in industrial sectors.

4.1. The Benchmark Model Regression

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Table 2. Benchmaek regression of carbon emission reduction effect of green finance

	（1）	（2）	（3）	（4）
	basic model	***Explanatory variable Lag one period***	***Urbanization, industrial structure and R&D expenses lag behind by two periods.***	***Final model***
lngf	-0.2529** （0.09）	-0.1885* （0.09）	-0.2642** （0.10）	-0.3521** （0.11）
lncity	0.1362 （0.15）	-0.0770 （0.16）	0.3309* （0.15）	0.3869* （0.17）
lngdp	-0.5953*** （0.05）	-0.5392*** （0.06）	-0.6720*** （0.06）	-0.6735*** （0.07）
lnFDI	-0.05** （0.01）	0.0535*** （0.02）	-0.0385** （0.01）	-0.0348* （0.01）
lnreg	0.0588*** （0.02）	0.0694*** （0.02）	-0.0593*** （0.02）	0.0576*** （0.01）
lnind	-0.0013 （0.09）	0.1839* （0.09）	0.1399 （0.09）	0.2293* （0.09）
lnrd	0.1644** （0.051）	0.0810 （0.05）	0.1673*** （0.05）	0.1731*** （0.05）
lncz	0.2761*** （0.07）	0.1170 （0.08）	0.2273** （0.07）	0.2650*** （0.08）
C	0.9046** （0.28）	0.3352 （0.31）	1.2405*** （0.32）	1.3104*** （0.36）

Note: *, * * and * * mean significant at the levels of 5%, 1% and 0.1% respectively.

As can be seen from Table 2, after fixed-effect regression of years and regions, the regression results are significant except for industrial structure (ind) and urbanization level (city), and the F test is significant, rejecting the original hypothesis and thinking that the fixed-effect regression effect is better than the mixed regression result. After random effect regression, the explanatory variable t test decreased significantly, and BP test was carried out, and the test result p value was 0. In this paper, hausman test is used to choose fixed effect model or random effect model. The test results show that the P value is 0, far less than 0.001, so the original hypothesis is rejected and the fixed effect model is selected for regression analysis. The t-test for industrial structure (ind) and urbanization level (city) is not significant. Considering that the transformation of industrial structure and urbanization process may have a lag effect on carbon dioxide emissions, all explanatory variables are taken as lagged and fixed effect regression is performed again. The proportion of urbanization level, R&D expenses, and local fiscal expenditure in the explanatory variables with a lag of one period is still not significant. Therefore, the analysis of urbanization level, industrial structure, and R&D expenses with a lag of two periods is conducted.

4.2. Model determination and interpretation

Model interpretation is based on the benchmark regression results in Table 2, and column (4) in Table 2 is selected as the final model interpretation variable coefficient. This model eliminates the interference of urban and time-invariant factors by taking urbanization level (city) as two periods, industrial structure (ind) as three periods, R&D expenditure (rd) as two periods and local fiscal expenditure (cz) as one period. At the same time, this paper adds urban fixed effect and time fixed effect. Column (4) of Table 2 shows that the influence coefficient of green finance on carbon emission reduction is -0.3521, which shows that green finance contributes to carbon emission reduction through 1% significance test. Economically significant, the probability of carbon emission reduction will increase by 0.3521 percentage points for every 1 percentage point increase in the green financial development index. Green finance supports the development of energy conservation and environmental protection, clean coal, carbon emission reduction and other fields through the role of capital orientation and environmental information disclosure, and promotes the green transformation of market players to help save energy and reduce carbon. The influence coefficient of urbanization level (city) is 0.3869, and the significance test of 5% shows that the improvement of urbanization level will increase carbon emissions.

The influence coefficient of GDP per capita is -0.6735, and the significance test of 0.1% shows that GDP growth contributes to carbon emission reduction and provides more financial support for green finance. It is worth mentioning that the fifth explanatory variable, that is, the development of industrial structure lags behind by three periods, and the reason why this variable needs to be selected by one period has been discussed above. The effect of carbon emission reduction is negatively affected by the fact that the industrial structure is three stages behind, and its influence coefficient is 0.2293, which is positive and passes the significance level test of 5%, indicating that the higher the level of industrial structure development, the lower the possibility of carbon emission reduction. From the economic point of view, every 1 percentage point increase in the development index of green industrial structure will reduce the probability of carbon emission reduction by 0.2293 percentage points. The reason may be that with the development of industrial structure, the demand for carbon emission will further increase, but at the same time, the carbon emission reduction technology has not been able to develop with it, resulting in the carbon emission reduction effect being lower than the demand for carbon emission, which is finally reflected in the decrease of carbon emission reduction effect with the increase of the proportion of industrial structure, that is, the secondary industry.

4.3. Heterogeneity analysis

The economic development of provinces in China is unbalanced, and the impact of green finance on carbon emissions may have regional differences. This paper will be divided into eastern, central and western regions to test the impact of green finance on regional heterogeneity of carbon emissions. Specifically, the virtual variable (virtual 1) is set, and the western region is set to 2, the central region is set to 1 and the eastern region is set to 0, thus generating three interactive variables, namely 0 (the eastern province of China), 1 (the central province of China) and 2 (the western province of China). At the same time, the interaction model is used to verify and observe three interaction variables (Table 3).

Table 3. Heterogeneity Analysis of the Impact of Green Finance on Carbon Emissions in Eastern, Central and Western Provinces of China

variable	coefficient	Standard error
city	***-1.7123****	***0.24***
gdp	***0.2289****	***0.11***
FDI	***-0.0769***	***0.03***
reg	***0.4148****	***0.03***
ind	***1.0752****	***0.19***
rd	***0.2105****	***0.06***
cz	***-0.2311****	***0.11***
0	***-0.2940****	***0.12***
1	***-0.3416***	***0.11***
2	***-0.1213***	***0.12***
c	***-2.4102****	***0.44***

Note: *, * * and * * mean significant at the levels of 5%, 1% and 0.1% respectively

As can be seen from Table 3, the influence coefficient of green finance in the eastern region is -0.2940, which has passed the 5% level significance test; the influence coefficient of interaction item in 1 (central province of China) is -0.3416, with a p value of 0.002, which has passed the 1% level significance test; the influence coefficient of interaction item in 2 (western province of China) is -0.1213, and the difference between the influence coefficient of interaction item in 1 (central province of China) and that in 2 (western province of China) is the largest. There are great regional differences in the carbon emission reduction effect of green finance development between the central provinces of China and the western provinces of China, and the carbon emission reduction effect of green finance development is more obvious in the central provinces of China. Combined with the eastern provinces of China, compared with the western provinces of China and the central provinces of China, the green financial index coefficient of the eastern provinces of China is slightly lower than that of the central provinces of China, but it is still much higher than that of the western provinces of China, indicating that the central provinces of China also have better carbon emission reduction effects.

5 Conclusions and suggestions

Based on the panel data of 30 provinces in Chinese mainland from 2005 to 2020 (excluding Tibet, Hong Kong, Macao and Taiwan due to lack of data), this paper discusses the relationship between green finance, industrial restructuring and carbon emissions, and draws the following conclusion: the development of green finance in China has a significant inhibitory effect on carbon emissions. Heterogeneity test shows that there are regional differences in the above inhibition effects, and the central region has the most obvious inhibition effect on carbon emissions, followed by the eastern and western regions. It is suggested to improve the green and low-carbon financing system; Improve the supervision system of green finance, standardize the green financial market, strengthen risk management and prudent supervision, and guard against risks in the field of green finance. Formulate policies according to local conditions and regions; Provide relevant policy and financial support for technologies that reduce carbon emissions, and promote the development of carbon emission reduction technologies ([4-5]).

6 Discussion

The effect of green finance on industrial carbon emissions in China based on provincial panel data has been analyzed in this paper. Meanwhile, other contents, such as indirect impact channels and spatial spillover effects, are worth further in-depth research. It is also should be paid attention to how to increase medium and long-term financial support, and promote substantive green innovation for enterprises. Financial institutions should continue expanding the scale of green credit, set targets for green loan growth, and innovate green financial products

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