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Research Article

Exploring the Role of Green Finance in Directly and Indirectly Mitigating CO2 Emissions: Evidence from China

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Abstract

This study analyses the direct and indirect influences of green finance on CO2 emissions. Panel data from the 30 provinces in China covering 2000 - 2020 are used in this paper. The empirical results indicate that green finance not only directly reduces CO2 emissions, but also has indirectly impacts via the scale, technical, and structural effects. A comprehensive green finance investment policy for strengthening environmental responsibility and for funding green technology is necessary for a successful energy transition to meet China's sustainable development goals.

Key words: green finance; CO_2 emissions; influencing mechanism

JEL classification codes:

1. Introduction

Since opening up in the late 1980s and the deepening of reforms, China's economy has developed at an annual rate of more than 9% in the subsequent 30 years (Wang et al., 2015; Chen et al., 2019). However, this economic growth has been attended by excessive energy utilization, resulting in high carbon dioxide (CO2) emissions that have caused increasingly severe environmental problems, such as air pollution and climate change (Kalkuhl and Wenz, 2020; Mukhtarov et al., 2022). Indeed, China has turned into the world's largest energy consumer and biggest producer of CO2 (Xiao et al., 2017; Wu et al., 2022). In 2020, China accounted for 26.1% of global energy demand and 30.9% of global emissions, and its share of the world's energy consumption is rising. Although the Chinese economy is the second largest in the world, it still lags behind developed economies in terms of environmental governance. How to balance economic development and environmental protection has thus become a pressing topic for scholars and policymakers.

Faced with international pressure to curb CO2 emissions and the consequences of domestic energy shortages and greenhouse gas emissions, the Chinese government has implemented a series of emission reduction measures. During the 11th Five-Year Plan (2006 - 2010) and 12th Five-Year Plan (2011-2015), China gained extraordinary headway in diminishing carbon intensity (measured as CO2 per unit of GDP). However, maintaining these gains is challenging in the post-COVID-19 period, since the accessibility and availability of green finance are assumed to have declined as financial strategies, government spending plans, and industry incomes come into question. (Taghizadeh-Hesary et al., 2021; Madaleno et al., 2022).

To aid sustainable economic development, the financial sector has launched financial instruments that explicitly target environmental assurance, such as green securities, green insurance, green bonds, and green credit card. Although China began to develop green finance in the 1990s, it was only in 2016 that the People's Bank of China together with others provided the Guiding Opinions on Building a Green Finance System, which was the focus of the G20 summit in the same year.

Green finance has changed the traditional investment channel, as governments at all levels and financial institutions attach equal importance to economic and environmental benefits. In particular, green credit and green investment play a leading role in promoting sustainable economic development (Yao and Tang, 2021; Saeed Meo and Karim, 2022).

Thus, this study investigates the degree to which green finance influences CO2 emissions and proposes policy recommendations to achieve China's emission reduction targets. Our main contributions are two-fold. First, despite the vast literature on the connections among CO2 emissions and green finance (Taghizadeh-Hesary et al., 2021; Gholipour et al., 2022; Sun and Chen, 2022), empirical studies on the influence mechanism between green finance and CO2 emissions are lacking. This study bridges this gap in the body of knowledge. Second, this study contributes to the mediating effect of

green finance on CO2 emissions by analyzing the scale, technical, and structural effects.

The remainder of this paper is structured as follows, Section 2 presents the data used and experimental strategy. Section 3 presents and discusses the empirical findings. Section 4 presents the study's conclusions and discusses the policy implications.

2. Variable Selection and Empirical Methodology

2.1. Variable selection and descriptions

We use the dependent variable of per capita CO2 emissions. The independent variable is green finance, which is constructed by the following four indices: green credit (the proportion of premium use in energy intensive industries), green investment (investment in environmental pollution control as a percentage of GDP), green insurance (the depth of agricultural insurance), and government support (the proportion of environmental protection expenditure) (Yang, Su, and Yao, 2021).

The control variables include the level of economic development (Shahbaz et al. 2013), energy consumption (Loures and Ferreira, 2019), urbanization level (Liang and Yang 2019), and population aging level (Liang and Yang 2019). Higher economic development, energy consumption, urbanization, and population aging correspond to higher CO2 emissions. Therefore, the signs of these variables are expected to be positive.

As the instrumental variables: In order to solve possible endogeneity problems, we select first and second order lag of independent variable following Zhou et al. (2022). In addition, we select economic size, technology level, and industry structure as the mediating variables to test how the scale, technical, and structural effects influence CO2 emissions (Dou et al. 2021). Table 1 presents the variable definitions, such as variable symbol and data source and Table 2 presents the descriptive statistics.

Variable type	Variables name	Variables symbol	Data source
Dependence variable	Per CO_2 emissions	$LnCO_2$	https://www.ceads.net.cn/
Independence variable	Green finance Index	lnGF	The authors calculate
Control variable	Economic development	lnED	https://www.epsnet.com.cn/index.html#/Index
	Energy consumption	lnEN	https://www.ceads.net.cn/
	Urbanization level	lnURB	https://www.epsnet.com.cn/index.html#/Index
	Population aging	lnAG	https://www.epsnet.com.cn/index.html#/Index
Instrumental variable	Lagged of green finance	L.lnGF	The authors calculate
Mediation variable	Economic scale	lnGDP	https://www.epsnet.com.cn/index.html#/Index
	Technical level	lnTFP	The authors calculate
	Industry structure	lnSTR	https://www.epsnet.com.cn/index.html#/Index

Table 1: *Variable definitions.*

Note: Organized by the author

Variables	Mean	Std.Dev.	Min	Max	Observable
$lnCO_2$	5.1858	0.8165	2.7306	6.6443	630
lnGF	-2.0762	0.5155	-3.1701	-0.1755	630
lnED	10.1565	0.8726	7.8867	12.0130	651
lnEN	6.9119	0.8814	3.7431	8.8666	630
lnURB	3.8920	0.3184	2.9705	4.5116	651
lnAG	-3.6371	1.2866	-7.1486	0.3289	651
lnGDP	18.2428	1.2648	13.9778	20.8867	651
lnTFP	1.4914	0.7438	0.0506	2.9801	651
lnSTR	0.0943	0.3806	-0.6405	1.6965	651

Table 2: *Descriptive statistics of the variables (after logarithm).*

Note: Std.Dev. Denotes standard deviation.

2.2. Empirical model

A panel regression model is utilized or the estimation in this section. According to the regression stochastic effects of population, affluence, and technology model (Dietz and Rosa, 1997), population and economic movement are the two most significant factors affecting CO2 emissions. Further, studies have adopted such influencing factors as energy use (Ang, 2007; Farhani, Chaibi, and Rault, 2014; Doğan et al. 2022), and financial development (Kim, Wu, and Lin 2020). The multivariate framework used in this study is as follows:

$$CO_{2it} = f(GF_{it})$$

(1) To lessen the risk of heteroskedasticity, we adopt normal logarithms. Hence, the benchmark regression model can be presented as follows:

$$\ln(CO_{2it}) = \beta_0 + \beta_1 \ln(GF_{it}) + \beta \vec{X} + \varepsilon_i + \mu_{it}$$

(2) where the subscripts i and t denote the province and year, respectively; β_1 is the parameter to be estimated; CO2 represents per capita CO2 emissions; and GF is the green finance index. X is the vector of the control variables. ε_i represents the individual fixed effects, and μ_{it} represents the error term.

To ascertain the influencing mechanism of green finance on CO2 emissions, Eqs. (3), (4), and (5) analyse the mediating effects of economic size, technology level, and industry structure.

Following Dou et al. (2021):

$$\ln(CO_{2it}) = \alpha_0 + \alpha_1 \ln(GF_{it}) + \alpha \vec{X} + \mu_{it} \quad (3)$$

$$\ln M_{it} = \gamma_0 + \gamma_1 \ln(GF_{it}) + \gamma \vec{X} + \mu_{it} \quad (4)$$

$$\ln(CO_{2it}) = \beta_0 + \beta_1 \ln(GF_{it}) + \beta_2 \ln M_{it} + \beta \vec{X} + \mu_{it} \quad (5)$$

where i and t signify the province and year, respectively, and $\vec{X}$ denotes a vector of the control variables. In theory, policy instruments usually act on the final through the transmission of relevant mechanism variables (Zhou et al. 2022). The dependence variable is CO2 emissions, and green finance is a means to control CO2 emissions, while green finance needs to achieve the goal of reducing CO2 emissions through the mechanism variable M. α and γ respectively measure the marginal effect of green finance on **β1** and mechanism variable M. If these two statistical coefficients are significant, then M can be considered as a mechanism for green finance to affect CO2 emissions. Eq.(5) is used to test the effect degree of mechanism M. In this study, mechanism variables M include economic scale, technology, and optimization of industrial structure, which represent scale effect, technology effect, and structure effect, respectively.

Different with Dou et al. (2021), we employ the economic scale to symbolize the scale effect instead of the total volume of imports and exports, and the total factor productivity (TFP) to symbolize the technical effect instead of the energy consumption intensity. Kalkuhl and Wenz (2020) suggested that annual gross product could measure the economy activity on the regional level. Lee and Lee (2022) suggested that TFP can be interpreted as a measure of technological change or technology dynamics.

3. Empirical Results

3.1. Estimation results

Table 3 shows the benchmark regression results. Per capita CO2 emissions are the dependent variable. First, with the OLS estimator results in Column [1], the coefficient of independent variable is significant at 1% level, except for urbanization level. Second, in order to control individual differences between provinces, we controls for the fixed effect, and excludes the control variables. The experimental results are displayed in Column [2]. Third, the control variables are gradually introduced into the model, and the regression results are shown in Columns [3] to [6]. We observe that the coefficient of green finance is significantly negative at the 1% level, showing that green finance significantly mitigates CO2 emissions. Moreover, a 1% improvement in the green finance level brings about a 0.3661% reduction in CO2 emissions (see Column (6)).

Hence, developing green finance is a viable strategy to mitigate CO2 emissions. In addition, the economic development level, energy consumption, urbanization level, and population aging level increase CO2 emissions, which are consistent with the findings of Balsalobre-Lorente et al. (2018), Pao and Tsai (2010), and Ajmi et al. (2013), who found that CO2 emissions are reduced by green finance and increased by energy consumption and economic growth.

Var.	(1)		(2) Scale effect		(3) Technical effect		(4) Structure effect		(5)
	lnCO2		ln*Vot*	lnCO2	ln*Te*	lnCO2	ln*Str*	lnCO2	lnCO2
lnGF	-0.1913*** (0.0481)		0.3425*** (0.0996)	-0.3557*** (0.0972)	0.1870** (0.0783)	-0.1968*** (0.0483)	0.4036*** (0.0601)	-0.1106** (0.0535)	-0.3280** (0.1292)
ln*Vot*				-0.2701*** (0.0599)					-0.4286*** (0.0663)
ln*Te*						0.0132** (0.0060)			-0.0113** (0.002)
ln*Str*								-0.1884** (0.0723)	-0.1863** (0.0710)
C	YES		YES	YES	YES	YES	YES	YES	YES
_cons	-11.0146*** (0.6139)		6.5259*** (0.7888)	-11.1709*** (0.9482)	0.0258 (0.6046)	-11.0050*** (0.6101)	2.0356*** (0.5268)	-10.6302*** (0.6105)	-10.4241*** (1.1848)
R^2	0.8980		0.9852	0.8934	0.0489	0.8985	0.4346	0.9061	0.8788
Obs	598		569	569	598	598	598	598	596

Table 3 *Benchmark regression.*

Note: *** and * indicate statistical significance at 1% and 10% levels, respectively.

3.2. Robustness check

In this section, we check the robustness of the test results in three ways. First, we employ the FMOLS and FGLS estimators to repeat the regression in Section 3.1. Second, we set total CO2 emissions as

the independent variable and employ OLS to estimate the variable coefficients. Finally, We also performed robustness analysis by applying 5% bilateral tail indentation to the variables.

Table 4 shows that the coefficients of green finance are negative and significant, but with some differences. By the FMOLS and FGLS estimator, shown in Column (1) and (2), we find that increase in green finance mitigates in per capita CO2 emissions. Further, using the OLS estimator, a 1% increase in green finance is associated with a 0.1271% decrease in total CO2 emissions, shown in Column (3). Finally, employing the bilateral shrink tail, shown in Column (4), a 1% increase in green finance is associated with a 0.2297% decrease in per capita CO2 emissions. This analysis demonstrates that green finance can reduce CO2 emissions to a certain extent (Saeed Meo and Karim 2022).

Variable	FMOLS	FGLS	OLS_Total	Bilateral shrink tail
	(1)	(2)	(3)	(4)
lnGF	-0.6854***	-0.7884***	-0.1271**	-0.2297***
	(0.1125)	(0.0354)	(0.0487)	(0.0634)
lnED	0.4183***	0.5045***	0.1848**	0.3148**
	(0.1106)	(0.0293)	(0.0763)	(0.1175)
lnEN	0.4776***	0.1950***	0.6219***	0.3469**
	(0.0621)	(0.0170)	(0.1025)	(0.1212)
lnURB	0.4539	0.6620***	0.0509	0.0448
	(0.2985)	(0.0675)	(0.1785)	(0.2780)
lnAG	-0.3976***	-0.0841***	-0.0044**	-0.0057
	(0.0346)	(0.0108)	(0.0021)	(0.0037)
_cons	-16.5806***	-14.5920***	-3.3443***	-10.3215***
	(1.0396)	(0.2863)	(0.6764)	(0.8035)
R^2	0.3075		0.9058	0.8243
Obs.	627	628	628	628

Table 4 *Robustness results*

Note:*** and ** indicate statistical significance at 1% and 5% levels, respectively.

3.3. Endogeneity test

The above analysis provides a statistical basis for the development of green finance to mitigate CO2 emissions. When the level of emissions increase, green finance may be paid attention growth increase and the level of green finance will be improved. Therefore, there may be endogenous problems between green finance and CO2 emissions. In order to mitigate the potential endogeneity problems in the model, this study adopts two ways. First, we employ a series of control variables while assessing the model to reduce the opportunities for endogeneity resulting from overlooked factors. Second, we adopted the two-stage least squares (2SLS) and the GMM methods using instrumental variables.

Following past research (Bond, 1991; Yang et al., 2021), we utilize lagged green finance as instrumental variables in panel data. The used of lagged variables at time t-d fulfills the criteria of a valid instrumental variable, as they should be connected with the endogenous variable at time t, but are not associated with the error term at time t. Indeed, the independent variables of the lagging period are introduced to replace the informative factors of the on going time frame. Since the green finance level lagging behind the primary stage could antagonistically influence the green finance level in the last stage, this eliminates the influence of the ongoing stage somewhat, thereby subsequently reducing the issue of endogeneity.

As shown in Table 5, there are no significant differences between the magnitude and sign of the coefficient, indicating the robustness of the results. These results again show that the green finance level of the lagging term still mitigates CO2 emissions, consistent with the results of the baseline regression.

Through the above analysis, we conclude that green finance mitigates CO2 emissions, which is consistent with the findings of Saeed Meo and Karim (2022) and Mamun, Boubaker, and Nguyen (2022). We further analyse the influencing mechanism of this relationship through the scale, technical, and structural effects in Section 3.4.

Variable	2SLS	GMM
lnGF	-1.0281*** (0.0529)	-1.0429*** (0.0528)
lnED	0.6193*** (0.0502)	0.6386*** (0.0501)
lnEN	0.2224*** (0.0222)	0.2151*** (0.0220)
lnURB	0.6628*** (0.0899)	0.6667*** (0.0902)
lnAG	-0.1079*** (0.0141)	-0.1061*** (0.0.0140)
Cons	-16.6084*** (0.4909)	-16.7746*** (0.4912)
obs	540	540
Hansen J	0.0120	0.0120

Table 5 *Endogeneity test*

Note:*** indicates statistical significance at 1% levels.

3.4. Influencing mechanism test

The mechanism effect results in Table 6 show that green finance mitigates CO2 emissions through all three effects. Thus, green finance and CO2 emissions have a significant negative correlation (Mamun, Boubaker, and Nguyen 2022).

For the scale effect, expanding green finance significantly increases economic size and decreases CO2 emissions. When the other factors are held constant, economic size increases by 0.3425% for every 1% increase in green finance. Through the mediating effect of economic size, the marginal impact of green finance on CO2 emissions rises. Specifically, the continued extension of green finance practices may increase economic performance by increasing economies of scale (Srivastava et al. 2020; Yang et al. 2021). In developing countries, when economies have grown, emissions have fallen (Narayan, Saboori, and Soleymani 2016; Narayan and Narayan 2010).

For the technical effect, the results indicate that green finance increases technological efficiency and reduces CO2 emissions, consistent with the results of Y. Wang et al. (2021). According to the results in Column [3], a 1% improvement in green finance, translates into a 6% improvement in technology. Although the coefficient of technological progress is positive, the value is very low. To mitigate CO2 emissions, the production process should be improved by investing in technological innovation and capital stocks (Shahbaz et al. 2019).

For the structural effect, increasing green finance can significantly increase the proportion of the secondary industry, which can help reduce CO2 emissions according to Xiao et al. (2017). Advanced technology and abundant financial assets brought about by green finance provide an opportunity for the secondary industry to develop low-carbon technologies (Dou et al. 2021). The results in Column [4] show that the marginal impact of green finance is smaller than expected, which is not consistent with the desired result.

In Column [5], we consider economic size, technological level and industrial structure, simultaneously. The marginal impact of green finance on reducing carbon emissions is 0.3280%. To summarize, green finance not only directly decreases CO2 emissions, but also lowers such emissions indirectly through the scale, technical, and structural effects.

Var.	(1)		(2) Scale effect		(3) Technical effect		(4) Structure effect		(5)
	$\ln CO_2$		$\ln Vot$	$\ln CO_2$	$\ln Te$	$\ln CO_2$	$\ln Str$	$\ln CO_2$	$\ln CO_2$
lnGF	-0.1913*** (0.0481)		0.3425*** (0.0996)	-0.3557*** (0.0972)	0.1870** (0.0783)	-0.1968*** (0.0483)	0.4036*** (0.0601)	-0.1106** (0.0535)	-0.3280** (0.1292)
ln*Vot*				-0.2701*** (0.0599)					-0.4286*** (0.0663)
ln*Te*						0.0132** (0.0060)			-0.0113** (0.002)
ln*Str*								-0.1884** (0.0723)	-0.1863** (0.0710)
C	YES		YES	YES	YES	YES	YES	YES	YES
_cons	-11.0146*** (0.6139)		6.5259*** (0.7888)	-11.1709*** (0.9482)	0.0258 (0.6046)	-11.0050*** (0.6101)	2.0356*** (0.5268)	-10.6302*** (0.6105)	-10.4241*** (1.1848)
R^2	0.8980		0.9852	0.8934	0.0489	0.8985	0.4346	0.9061	0.8788
Obs	598		569	569	598	598	598	598	596

Table 6 *Results of the mediating effects in the green finance-CO2 nexus*

Note: The value in parentheses represent Std.Err. ***indicate statistical significance at 1% level. ** indicate statistical significance at 5% level. C include control variables.

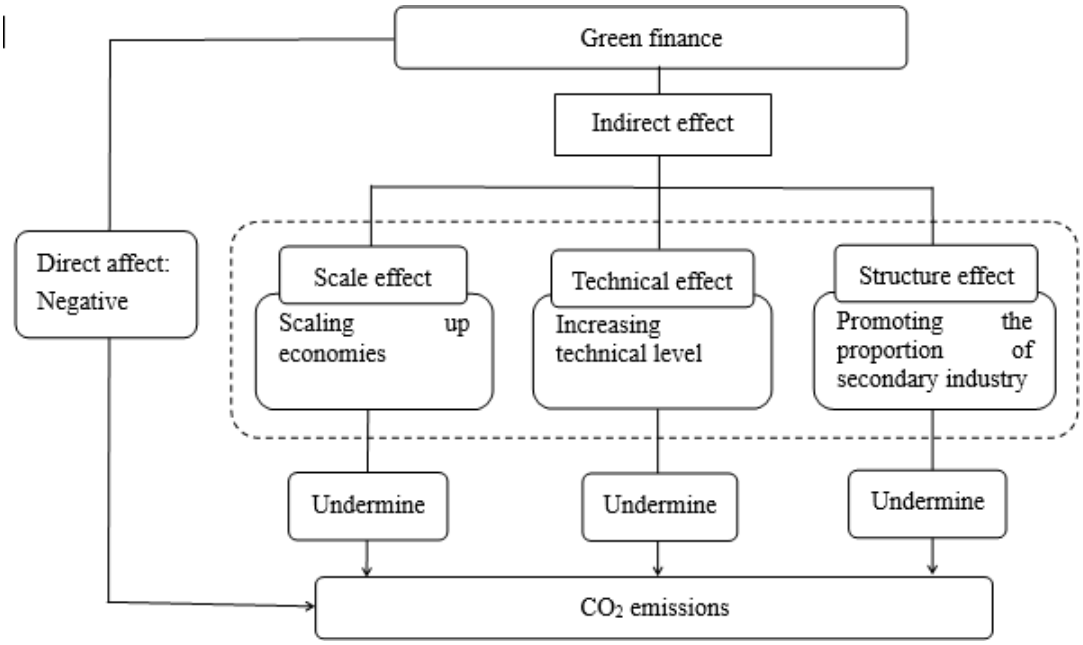

Figure.1. *Schematic diagram of the mediation effect.*

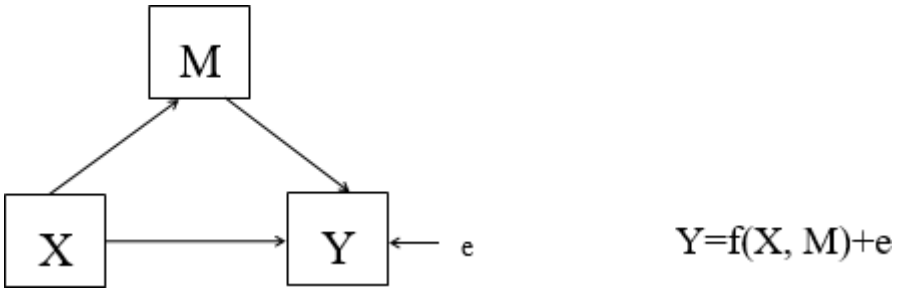

Figure.2. *Impact mechanism from green finance to CO2 emissions.*

4. Conclusions and Policy Implications

In this study, using panel data from the 30 provinces in China covering 2000 - 2020 to assess the influence of green finance on CO2 emissions, the outcomes led to two main findings: First, green finance directly reduces CO2 emissions. Second, green finance promotes economic development, technology development and the optimization of the industrial structure, and then reducing CO2 emissions. In summary, concurring with Madaleno, Dogan, and Taskin (2022), a comprehensive green finance investment policy for strengthening environmental responsibility and funding green technology is necessary for successful energy transition and to meet China's sustainable development goals. However, it is important to reinforce the supervision of green finance to accomplish the country's emission reduction targets.

Based on the findings above, several policy implications are highlighted as follow. First, green finance mitigates of CO2 in China. Thus, to jointly achieve a carbon reduction target, it will be necessary to encourage and regulate green finance in China. More specifically, the government should promote green financial knowledge and guide the circulation of green financial assets. Second, through the mechanism effect analysis, scale effect and technological effect are conductive to mitigate CO2 emissions, which indicate that policy makers should develop economic and technology by green finance. Additionally, governors should think highlight of the industrial structure and encourage second industry to instead the high energy consumption, high emission, and high pollution industry.

Although this study has demonstrated that development green finance mitigate emissions of CO2 in China, some limitations still exist. While, the environmental policy, green finance development, and economic development are different in each province. However, this study has not discussed each province's green finance-CO2 relationships separately. Thus, in future research, it could aim at environmental policies and green financial instruments in different regions, the impacts of green finance on carbon emissions under different backgrounds are analyzed more specifically.

Author statement

Jingrong Tan: Funding acquisition, Conceptualization, Methodology, Visualization, and Software.

Lin Chen: Conceptualization, Supervision, Validation, Investigation,Writing-Original draft preparation and Editing.

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