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Research on the carbon emission reduction effects of green finance in the context of environment regulations

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ABSTRACT

The rise in carbon emissions has significantly aggravated issues related to climate change. In light of this background, there has been a strong focus on using financial methods to reduce carbon emissions. Based on panel data for China for the period 2003–2019, we examine the effects of green finance on carbon emissions and the moderating effects of environmental regulations. The results indicate that green finance development alleviates carbon emissions. Meanwhile, our findings on the effects of green finance policies suggest that the implementation of such policies will strengthen the carbon-emission reduction effects of green finance. Additionally, the impacts of green finance on carbon emissions are moderated by administration and public-oriented environmental regulations rather than market-oriented environmental regulations. As the biggest emitter of carbon emissions in the world, China should prioritise the consistent and steady development of green finance and facilitate the green finance legislation. Furthermore, China should enhance the role of market-oriented environmental regulations while considering the synergy between environmental regulations and green finance.

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1. Introduction

Global warming, induced by greenhouse gases (GHGs), has raised global temperatures by 1.1°C above pre-industrial levels, resulting in a series of environmental issues such as rising sea levels, increased volatility of agricultural output, environmental degradation and natural disasters such as droughts, tsunamis and floods. To address these issues, at the 2015 United Nations (UN) Climate Change Conference (COP 21), 195 participating countries signed the Paris Agreement to promote the mitigation of GHGs and thereby limit the increase in global temperature to well below 2°C above pre-industrial levels. Additionally, at the 2021 UN Climate Change Conference (COP

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26), more than 200 countries reached the Glasgow Agreement, which further stresses the importance of having global adaptation goals for the effective implementation of the Paris Agreement. Considering that carbon emissions (CE) account for 74% of GHGs[1], alleviating CE is of utmost significance for GHGs reduction.

The Paris Agreement initially emphasised the role of the financial sector in reducing CE; subsequently, academics and policy-makers gradually reached the consensus that capital plays a dominant role in the alleviation of CE (Dong et al., 2021). However, it is difficult for traditional financial markets to allocate resources for low-carbon programmes due to the high uncertainty, low returns and serious externalities associated with such programmes (Sachs et al., 2019), particularly in countries with immature and under-capitalised financial markets, which may significantly impede the investment flow into green fields. Compared with traditional financial instruments, green finance (GF) focuses on ecological and environmental responsibilities and can provide adequate and sustainable financing for low-carbon measures such as research and development (R&D) in green technologies, construction of clean energy infrastructure, etc. Consequently, it has been viewed as a powerful weapon to fight against CE in recent decades.

Additionally, as an administrative way of realising low-carbon development, environmental regulations (ER) may affect the relationship between GF and CE (Fang and Shao, 2022). In the context of strict ER. Environmental protection administrations could penalise enterprises that attempt to seize GF funds by merely adopting terminal governance or greenwashing. In this way, ER promotes the efficiency of green capital and facilitates the low-carbon transition of economy. Meanwhile, the compliance costs of high-emission enterprises may gradually exceed the subsidy effect of GF under the background of ER, forcing them to invest in green technologies and realise low-carbon production (Yang et al., 2022). In these ways, ER may moderate the effect of GF on CE.

As the largest carbon emitter in the world, China's CE has soared from 3128 million tonnes in 1997 to 10523 million tonnes in 2021, accounting for 28.98% of global emissions and nearly 2.5 times that of the second largest emitter in the world—USA[2]. Clearly, China is facing huge environmental challenges that are of concern to the international community; thus, CE reduction in China plays a pivotal role in the mitigation of global CE and climate change. In 2020, China pledged to reach its peak CE by 2030 and committed to becoming carbon neutral by 2060. However, these goals cannot be achieved without the support of GF and ER, especially considering that China still faces considerable pressure related to economic growth. Thus, exploring a viable CE reduction mode will not only address severe climate change issues, but also offer the solutions enacted in China to other countries to realise their own green economy transformation via financial methods. Additionally, investigating the moderating role of ER can provide lessons for developing countries to strengthen the synergy between GF and ER when realising their low-carbon transition. (Figures 1 and 2)

This study makes the following contributions to literature. First, this paper distinguishes itself from previous studies by examining both the current and time-lag effects of GF. The results indicate that GF could reduce CE in both the short and long-terms, providing evidence for the government to facilitate the consistent and steady development of GF. Second, we compare the CE-reduction effects of GF before

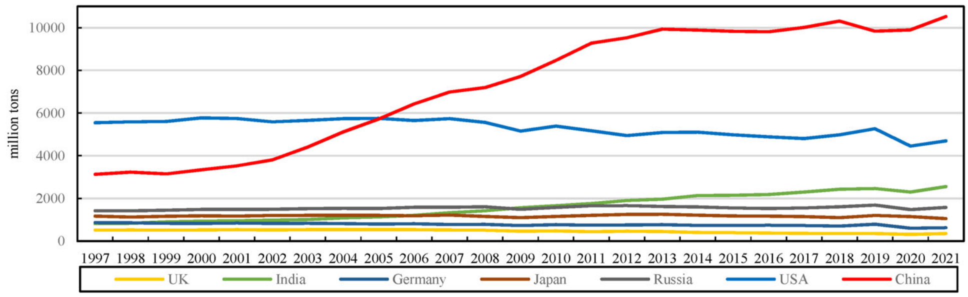

Figure 1. The top seven carbon emitters in the world.
Source: Economy Prediction System (EPS) Database.

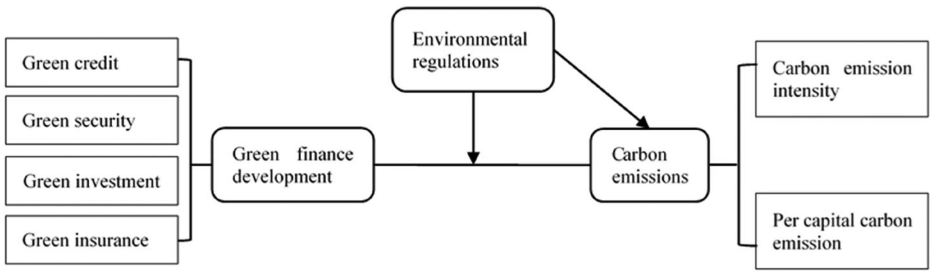

Figure 2. CE-reduction mechanism of green finance.
Source: Author's designed.

and after the implementation of green finance policies (GFP) to explore policy effects and demonstrate that the enforcement of GFP could facilitate the mitigation of CE, thus encouraging policy-makers to prompt GF-related legislation. Third, we investigated the heterogeneous moderating effects of different ER instruments on the relationship between GF and CE, revealing the synergistic effects of GF and ER and emphasising the importance of environmental policies in formulating and implementing CE reduction strategies.

The remainder of this paper is organised as follows. Section 2 presents a review of relevant literature, while Section 3 introduces the theoretical model. Section 4 describes the dataset, variables and statistical characteristics. Section 5 reports the main empirical results, while Section 6 summarises the main conclusions and presents the policy implications of the study's findings.

2. Literature review

2.1. Green finance development (GFD) and carbon emissions (CE)

With increasing concerns about global warming issues, significant attention has been paid to CE reduction (Xiu et al., 2015; Ren et al., 2020; Li et al., 2021; Meo & Abd Karim, 2022). Since GF emphasises the balance between economic development and environment protection, policy-makers and academics consider it as a powerful weapon to alleviate CE, thereby contributing to the realisation of sustainable development (Sachs, 2015; Falcone et al., 2018; Xie & Liu, 2019). Xiu et al. (2015) highlighted that green credit policies contribute significantly to emission reduction and energy conservation under the constraints of industrial growth. Similarly, Ren et al. (2020) stated that GFD in China would increase the use of non-fossil energy, which could significantly contribute to a decline in CE. Furthermore, Meo & Abd Karim (2022) found that green bonds have a negative impact on CE in the top 10 economies in the world that support GF. However, few studies focus on measuring GF comprehensively.

Theoretically, GF can reduce CE in two ways. First, GFD improves the loan threshold for high-emission enterprises and increases their liquidity constraints, forcing them to downsize their scale of production or carry out low-carbon transformation, thus reducing their CE (Dikau & Volz, 2018). Liu et al. (2017) found that green credit policies effectively curb investment in energy-intensive industries, thereby decreasing CE. Second, GFD can stimulate more green capital flows from the financial sector into the enterprise sector (Nassiry, 2018). Specifically, GF can ease the liquidity constraints of low-emission enterprises by providing them with more financial resources, which indirectly leads to a decrease in CE by facilitating low-carbon technologies innovation (Schmidt, 2014; Yu et al., 2021; Musah et al., 2022).

Previous studies typically used a single GF instruments, such as green credit, green bonds or green insurance, as a proxy for GFD (Flammer, 2021; Wang & Guo, 2022). However, although single indicator can reflect GFD to a certain extent, they do not reveal the overall picture of GFD. To this end, it is imperative to establish an evaluation system to comprehensively measure the level of GFD. Moreover, scholars tend to mainly focus on current effect of GF; however, given the time-lag effects of financial instruments, the long-term effect of GF should also be considered. Additionally, the impact of the policy effects of GF on CE has also been neglected in prior literature. Financial legislation can provide an institutional guarantee for GFD, which will ultimately alleviate CE.

2.2. The role of environmental regulations (ER)

In general, ER can mitigate CE in two ways. First, environment rules and laws increase compliance costs and impact the profitability of enterprises through market-based methods such as taxes and penalties (Kozluk & Zipperer, 2014), which induce high-emission enterprises to adopt environmentally friendly technologies, invest more money into research on cleaner production and develop a green industrial chain with low levels of pollution (Liu et al., 2021), thereby reducing CE. Additionally, ER can promote the production of low-emission enterprises though subsidies and incentives, thus alleviating the CE at the same time. Second, ER can also prohibit production of high-emission enterprises through administrative measures (Ren et al., 2018; Rehman et al., 2021), which downsizes the scale even withdraws the high-emission enterprises from the market and decreases the CE directly (Bai et al., 2014).

Since CE reduction is a systematic process that involves capital, laws, industries, etc., it is important to highlight the moderating role of ER in the relationship between GF and CE. Enterprises tend to invest in high-emission projects rather than low-carbon projects when the compliance cost of the former is greater than the return obtained from the latter (Wang et al., 2021). However, in the context of strict ER, enterprises are compelled to upgrade their production with environmentally friendly technology. Consequently, they tend to turn to GF for meet ER (Noh, 2018). However, strict ER also facilitates the development of low-emission enterprises, not only helping them to obtain money from financial institutions, but also easing liquidity constraints and expanding their production scale (Falcone, 2020).

Although previous literature has emphasised the importance of ER in alleviating CE, discussions about the synergistic effect of GF and ER on CE reduction are limited. Considering that the existence of ER can effectively address the deficiencies of GF by administrative means, the role of ER should not be overlooked when discussing the effect of GF on CE. In other words, it is necessary to examine the moderating role of ER in the relationship between GF and CE. Additionally, there are limited studies that focus on the heterogeneous effects of different ER instruments, which is an issue that should be explored in depth since it is valuable for precisely formulating environmental protection policies.

3. Theoretical model

We develop a general equilibrium model to investigate the relationship between GF and CE in the context of ER.

3.1. Basic settings

3.1.1. Resident sector

We set the consumer utility function as follows:

$$U = \frac{C(t)^{1-\sigma} - 1}{1-\sigma}, \quad \sigma > 0 \tag{1}$$

In Equation (1), C represents consumption and σ is the coefficient of relative risk aversion.

3.1.2. Production sector

Like most economic growth models with environmental constraints, this study normalises labour to 1 and uses the AK production function as follows:

$$Q(t) = \Omega(E)Y(t) = \Omega(E)AK(t)_Y{}^{\gamma}, \quad 0 < \gamma < 1 \tag{2}$$

In Equation (2), $\Omega(E)$ is the output loss caused by the CE, represented by E. Obviously, $\Omega(E)$ increases continuously with E; therefore, we set $\Omega(E) = E(t)^{-\beta}$. Above all, $Q(t)$ can be given as follows:

$$Q(t) = E(t)^{-\beta} AK(t)_Y{}^{\gamma} \tag{3}$$

3.1.3. Carbon emissions (CE)

CE are generated by the activities of enterprises and can be given as follows:

$$E(t) = \frac{Y(t)}{H(t)} \tag{4}$$

In Equation (4), $E(t)$ is the CE at the t moment, while $H(t)$ is a function of CE-reduction technologies. Like other innovations, the R&D innovation of CE-reduction technologies has knowledge spillover effects. Thus, we incorporate Romer's setting of endogenous technological progress into CE-reduction technologies as follows:

$$H = A_h K(t)_H{}^{\mu} \tag{5}$$

In Equation (5), A_h represents the innovation capability parameter of the green innovation sector, while $K(t)_H$ represents the investment in the R&D of CE-reduction technologies, i.e. knowledge spillover, indicating that $\mu > 1$.

3.1.4. Green finance (GF)

In an economy, financial institutions absorb savings from households and provide loans for both enterprises and R&D sector related to CE-reduction technologies. The former pays interest through their profits, while the latter cannot pay interest since it is a non-profit sector. Here, we define loans provided by financial institutions for the latter as 'the environmental responsibility of financial institutions'. Thus, assuming that the financial sector is perfectly competitive, the profit of the financial sector is:

$$\pi_f = RK(t)_Y - rK(t) \tag{6}$$

In this study, we assume that environmentally responsible[3] financial institutions devote a certain proportion η of their capital towards the R&D of CE-reduction technologies, i.e. $\eta = \frac{K(t)_H}{K(t)}$ and $K(t)_Y = (1-\eta)K(t)$. The higher the η, the higher the level of environmental responsibility of financial institutions. R is the lending rate, while r is the deposit rate.

3.2. Competitive equilibrium

3.2.1. Decision of enterprises

Substituting the relationship between CE and production into Equation (2), we obtain:

$$Q(t) = A^{-\beta+1} A_h{}^{\beta} K(t)_Y{}^{\gamma-\beta\gamma} K(t)_H{}^{\beta\mu} \tag{7}$$

The maximisation of enterprise profit requires that the marginal product of capital be equal to the price of capital. Thus, we normalise the price of the final product to 1 and obtain the following equation:

$$Q(t)_{K_Y} = R = (\gamma - \beta\gamma) A^{-\beta+1} A_h{}^{\beta} K(t)_Y{}^{\gamma-\beta\gamma-1} K(t)_H{}^{\beta\mu} \tag{8}$$

3.2.2. Decision of financial institutions

In a perfectly competitive market, the zero-profit condition of financial institutions can be given as follows:

$$\pi_b = R_Y K(t)_Y - rK(t) = 0 \tag{9}$$

Hence, $R = \frac{1}{1-\eta} r$.

3.2.3. Maximisation of consumer utility

From Equation (1), we can infer the consumer utility maximisation function as follows:

$$\max \int_0^\infty \frac{C^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt$$
$$\text{s.t. } \dot{a} = ra - C \tag{10}$$

In Equation (10), a represents the wealth of residents. To solve this optimisation problem, we set a Hamiltonian function as follows:

$$H = \frac{C^{1-\sigma} - 1}{1-\sigma} + \lambda_1 (ra - C) \tag{11}$$

Then, the static and dynamic first-order conditions are $H_C = 0$ and $H_a = \rho\lambda_1 - \dot{\lambda}_1$. Consequently, $r = \rho - \frac{\dot{U_C}}{U_C}$.

3.2.4. Market equilibrium

The market equilibrium condition can be inferred by combining the market clearing conditions of resident, enterprise and financial sector:

$$(\gamma - \beta\gamma) A^{-\beta+1} {A_h}^{\beta} {K(t)_Y}^{\gamma-\beta\gamma-1} {K(t)_H}^{\beta\mu} = \left(\rho - \frac{\dot{U_C}}{U_C}\right) \frac{1}{1-\eta} \tag{12}$$

Solving Equations (4), (5), (8) and (12) simultaneously, we obtain:

$$(E/Q)^{\beta} = A^{\beta^2} {A_h}^{-\beta(1+\beta)} K^{-\beta\mu+\beta^2\gamma-\beta^2\mu} \eta^{-\beta\mu(1+\beta)} (1-\eta)^{\beta^2\gamma} \tag{13}$$

Taking the log of both sides, we obtain the following equation:

$$\begin{aligned} \ln(E/Q) = {} & \beta \ln A - (1+\beta)\ln A_h - (\beta\mu - \beta\gamma + \mu)\ln K - \mu(1+\beta)\ln\eta \\ & + \beta\gamma \ln(1-\eta) \end{aligned} \tag{14}$$

As shown in Equation (14), the higher the η, the lower the E/Q. This shows that the CE per unit of output decrease with an increase in 'the environmental responsibility of financial institutions'.

Meanwhile, solving Equations (4) and (5) simultaneously and calculating the log of both sides, we obtain the following equation:

$$\ln E = \ln A - \mu \ln A_h + (\gamma - \mu)\ln K - \mu \ln\eta + \gamma \ln(1-\eta) \tag{15}$$

As shown in Equation (15), the higher η, the lower E. This shows that CE decrease with an increase in 'the environmental responsibility of financial institutions'. Given that labour is normalised to 1, CE and CEPC are equivalent.

3.3. Competitive equilibrium in the context of environmental regulations (ER)

Under the background of ER, the proportion of capital lent by financial institutions for R&D related to CE reduction technologies depends on both environmental responsibility and ER, i.e. $\eta I = \frac{K(t)_H}{K(t)}$ and $K(t)_Y = (1 - \eta I)K(t)$, where I is the parameter of ER.

Repeating the derivation used in Section 2.2.4, we obtain the following equations

$$\ln(E/Q) = \beta \ln A - (1+\beta)\ln A_h - (\beta\mu - \beta\gamma + \mu)\ln K - \mu(1+\beta)(\ln \eta + \ln I) + \beta\gamma \ln(1 - \eta I) \tag{16}$$

$$\ln E = \ln A - \mu \ln A_h + (\gamma - \mu)\ln K - \mu(\ln \eta + \ln I) + \gamma \ln(1 - \eta I) \tag{17}$$

From the above equations, it can be concluded that both E and E/Q have negative relationships with η, I and ηI. This indicates that both carbon emission intensity (CEI) and carbon emission per capita (CEPC) decrease with an increase in environmental responsibility, ER and their interactive items.

4. Methodology

4.1. Data

CE data was estimated by Chen et al. (2020), we aggregated CE at the county level to obtain the corresponding CE data at the provincial level according to China's administrative divisions for the period 2003–2019. Green finance index (GFI) data were obtained from the China Statistical Yearbook, China Insurance Yearbook, Statistical Yearbooks, central and local government reports and the Wind database for the period 2004–2020, while ER data was obtained from the economy prediction system (EPS) database for the period 2003–2015. The control variables data was derived from National Bureau of Statistics of China, China Industrial Statistics Yearbook, China Energy Statistics Yearbook and government reports issues 2004–2020, respectively. The definitions and summary statistics of main variables are shown in Table 1.

4.2. Variables

4.2.1. Dependent variables

At present, CEI and CEPC are most effective instruments to evaluate CE. Hence, they were selected as dependent variables for our analysis.

4.2.2. Independent variables

To measure GFD in this study, we utilise GFI, which is a composite index comprising green credit, green security, green investment and green insurance. Related indicators and their definitions are presented in Table 2. To avoid the deviation of estimation coefficients, we expanded this index by 10 times in the empirical analysis.

Table 1. Definitions of variables and summary statistics.

Variables	Definition	Abbreviation	Mean	SE	Min	Max
Green finance index	The index of green finance	GFI	0.14	0.09	0.04	0.79
Carbon emission intensity	CE/GDP (ton/10000 yuan)	CEI	2.69	2.23	0.19	12.57
Carbon emission per capita	CE/population (ton/person)	CEPC	7.94	7.16	0.91	45.58
Urbanization rate	Urban residents/population	UR	0.52	0.14	0.24	0.89
Human capital	Number of college students/10000 person	HC	0.17	0.06	0.03	0.35
Foreign investment	Foreign direct investment (logarithm form)	FDI	0.81	1.46	0.01	13.47
Industrial structure	Added value of secondary and tertiary industries/the gross domestic product (GDP)	IS	1.03	0.57	0.49	5.16
Energy consumption	Energy consumption/population (ton/person)	EC	3.18	1.65	0.72	11.00
Environmental regulations	Index of environmental regulations	ER	0.55	0.05	0.37	0.75
Administration-oriented regulations	Frequency of environmental -protection words in government reports (logarithm form)	AR	3.67	0.39	2.48	4.66
Market-oriented regulations	Investment in pollution protection/industrial gross product	MR	1.53	1.34	0.02	9.91
Public-oriented regulations	Number of environmental petitions (logarithm form)	PR	7.02	1.26	1.09	9.11

Source: Author's calculated.

Table 2. Dimensions, indicators and definitions, including properties.

Dimensions	Indicators	Definitions	Properties
Green credit	Proportion of high energy-consuming industrial industry interest expenditure	Interest expenditure of six high energy-consuming industrial industries /Industrial industry interest expenditure	−
Green security	The proportion of market value of environmental protection enterprises	Market value of A shares of environmental protection enterprises /Total market value of A shares	+
Green investment	The proportion of pollution abatement investment	Pollution abatement investment /GDP	+
Green insurance	The proportion of the overall size of agricultural insurance	Agricultural insurance income / Gross value of agricultural output	+

Source: Author's calculated.

4.2.3. Moderating variables

Building on previous works (Chen et al., 2018; Tu et al., 2021), we select ER, AR, MR and PR as moderating variables to assess ER from the perspectives of entirety, the government, market and society.

4.2.4. Control variables

Considering that urbanisation, foreign direct investment and other factors may impact CE, we select UR, HC, FDI, IC, EC and ERI as the control variables, building on the works of Lu et al. (2019) and Shahbaz et al. (2020).

4.3. Descriptive statistics

4.3.1. Green finance development (GFD)

Figure 3 presents the GFI in China during the period 2003– 2019. Overall, GFI shows an upward trend, ranging from 0.04 to 0.79 with an average value 0.14, showing that, despite the dramatic advancements in GF in the 21st century, further improvements in GFD are

Figure 3. GFI in China for the period 2003–2019.
Source: Author's calculated.

required. However, it should be noted that GFI began to increase significantly after 2012, which may be closely related to the enactment of the green credit guidelines. Additionally, considering regional disparities, the three major financial centres in China, namely Beijing, Shanghai and Guangzhou, are ranked as the top three in terms of GFI and are significantly ahead of other provinces, which can be attributed to their high levels of traditional finance development. Meanwhile, although Chongqing and Shaanxi rank among the top 10 provinces in terms of GFI, the east-high and west-low trends have not changed fundamentally, which can be attributed to the differences in economic development.

4.3.2. Carbon emissions (CE)

Figure 4 shows the CEI in China for the period 2003–2019. Overall, the CEI decreased from 3.98 tonnes/10000 yuan in 2003 to 1.87 tonnes/10000 yuan in 2019, which may be attributed to the upgrade of the industrial infrastructure and the transformation of development mode. From the perspective of regional disparities, most provinces with a high CEI, such as Xinjiang, Ningxia, Liaoning and Heilongjiang, are located in northwest and northeast China, while eastern areas, such as Beijing, Tianjin, Shanghai and Guangdong, tend to have low CEI. The northeast and northwest regions are dominated by resource-intensive industries, which are highly dependent on fossil fuels, and thus, the CE per unit of GDP are high. In contrast, eastern regions are dominated by capital and technology-intensive industries, with relatively low dependence on fossil fuels. Thus, they tend to have a low CE per unit of GDP.

Figure 5 shows the CEPC in China for the period 2003–2019. Overall, the CEPC increased from 3.79 tonnes in 2003 to 10.71 tonnes in 2019. However, the growth rate of CEPC has slowed down significantly since 2012, which may be attributed to the fact that China has attached great importance to green development since the 18th National Congress of the Communist Party came into power and implemented

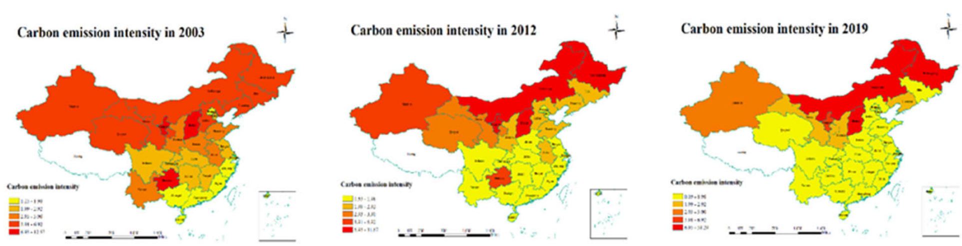

Figure 4. CEI in China for the period 2003–2019.
Source: Author's calculated.

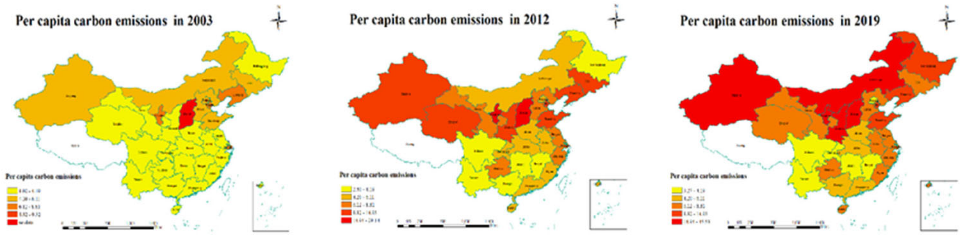

Figure 5. CEPC in China for the period 2003–2019.
Source: Author's calculated.

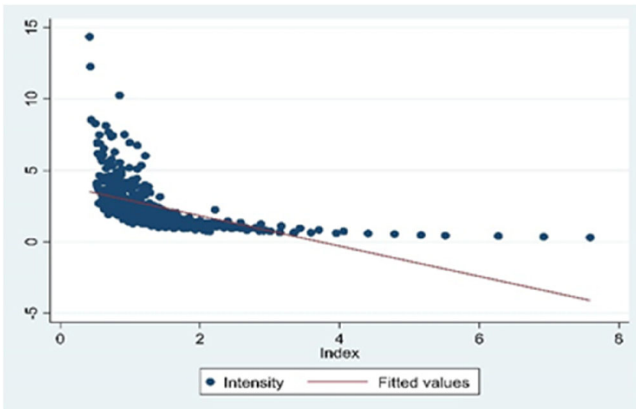

Figure 6. GFI and CEI.
Source: Author's calculated.

measures such as emission limitations and the shutdown of high-emission enterprises. Regarding regional disparities, provinces with a high dependence on fossil fuels, such as Inner Mongolia, Xinjiang and Shanxi, rank in the first echelon, with a CEPC of more than 10 tonnes. Provinces with heavy industries, such as Zhejiang, Jiangsu, Shandong, rank in the second echelon, with a CEPC of 5–10 tonnes. Other provinces, such as Jiangxi and Hainan, rank in the third echelon, with a CEPC of less than 5 tonnes.

4.3.3. Relationship between green finance (GF) and carbon emissions (CE)

Figure 6 shows the scatter distribution and regression line of GFI and CEI while Figure 7 shows the scatter distribution and regression line of GFI and CEPC. The above two figures show that the GFI has a negative correlation with CE and CEPC, which shows that GFD has an inhibitory effect on both of them. On the one hand, GFD can increase the financing constraints of high-emission enterprises and reduce their production and emission scale. On the other hand, GFD can provide funds for the R&D of low-carbon technologies and facilitate the green transition of economy.

5. Empirical results

5.1. The model

Based on Equations (14) and (15) in Section 3, we developed the following empirical model to examine the relationship between GF and CE.

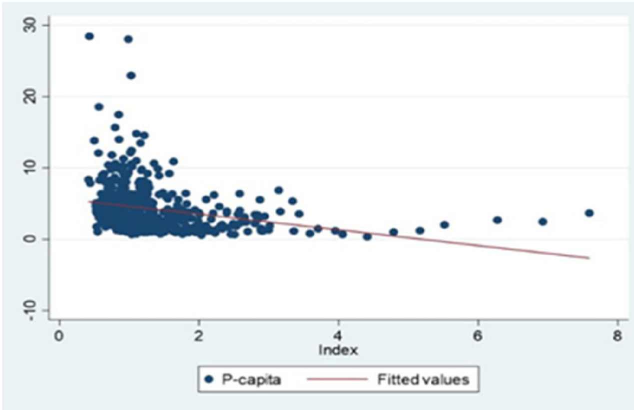

Figure 7. GFI and CEPC.
Source: Author's calculated.

$$CE_i = \alpha_0 + \alpha_1 GFI + \alpha_2 Cons + \varepsilon_0 \tag{18}$$

In the above equation, $i = 1, 2$ represents CEI and CEPC, respectively. α_0 is the constant, while α_1 and α_2 represent the coefficients. *Cons* refer to the controls variables, and ε_0 is residual term.

5.2. Baseline regression

Based on the results from the Hausman Test of Models (1)-(6), the values of p is 0.00, which significantly rejects the null hypothesis that the independent variables are not correlated with the residuals at the 1% level. Thus we adopt the fixed effect model to examine Equation (18). Models (1) and (2) report the regression results of the GFI on CEI and CEPC without adding any control variables. The regression coefficients of the CEI and CEPC are −0.09 and −0.22, respectively, which are significant at the 1% level, indicating that GFD has effectively decreased the CEI and CEPC. On the one hand, GF has a subsidy effect on green innovation. Financial institutions provide finance for enterprises to adopt low-carbon technologies that contribute to GFD, thereby accelerating the substitution of high-emission technologies and promoting the green transition of economy. On the other hand, GF has a crowding-out effect on the pricing of financial products. Financial institutions tend to increase the borrowing cost of high-emission enterprises by incorporating the environmental cost of CE into the price of financial products, forcing these firms to transmit to low-carbon technologies or withdraw from the market. Our findings are consistent with prior literature that focuses on single GF instruments such as green credit, green bonds, etc. (Flammer, 2021; Wang & Guo, 2022). Models (3) and (4) represent the results after adding control variables. Here, the regression coefficients of the CEI and CEPC are −0.03 and −0.16, respectively, which are significant at the 5% and 1% levels, respectively, indicating that, after including control variables, such as urbanisation, human capital, etc., into consideration, the CE-reduction effects of GF still works; however, the degree decreases. (Table 3)

Table 3. Green finance development (GFD) and carbon emissions (CE).

Variables	(1) CEI	(2) CEPC	(3) CEI	(4) CEPC	(5) CEI	(6) CEPC
GFI	−0.09*** (−9.06)	−0.22*** (−17.31)	−0.03** (−2.54)	−0.16*** (−7.60)	−0.03** (−2.12)	−0.15*** (−7.02)
GFI (−1)					−0.02* (−1.98)	−0.13*** (−6.04)
UR			−0.11*** (−15.68)	−0.16*** (−5.11)	−0.11*** (−16.92)	−0.16*** (−5.34)
HC			−0.05*** (−3.29)	−0.22*** (−3.21)	−0.05*** (−3.19)	−0.22*** (−3.16)
FDI			$1.00e^{-3}$*** (3.39)	$2.83e^{-3}$** (2.64)	$8.89e^{-4}$** (2.71)	$2.60e^{-3}$** (2.33)
IS			$8.14e^{-3}$*** (4.48)	0.01*** (3.78)	$7.64e^{-3}$*** (4.17)	0.01*** (3.39)
EC			0.01*** (11.27)	0.03*** (25.99)	0.01*** (11.36)	0.03*** (26.02)
Constant	0.04*** (25.66)	0.11*** (59.03)	0.04*** (32.62)	0.01*** (5.05)	0.04*** (32.24)	0.01*** (5.45)
Province	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
R^2	0.21	0.16	0.39	0.66	0.39	0.66
Observations	510	510	510	510	510	510

Source: Author's calculated.

We further select the lagged first-order GF as explanatory variables in models (5) and (6). It is found that the lagged first-order regression coefficients is still significantly negative, indicating that there are significant time-lag effects of GF on CE. First, there are time-lag effects on the flow of funds from financial sector to enterprise sector. Second, the implementation period of low-carbon projects is relative long. Finally, green credit is the largest component of GF; however, the effect of credit on the real economy has significant time-lag effects (Wen & Zhang, 2018). It is worth noting that little attention has been paid to the time-lag effects of GF in prior literature (Ren et al., 2020; Irfan et al., 2022).

For the control variables, urbanisation has a significant negative effect on CE. Scale effect caused by population agglomeration can effectively promote economic development and reduce CEI as well as CEPC. Human capital has a significant negative impact on CE. Human capital could facilitate the R&D of low-carbon technologies and arouse the environmental awareness of society, thereby inhibiting CEI and CEPC. FDI has a significant positive impact on CE. FDI may bring high-emission enterprises from advanced economy to developing countries due to lower ER, which is consistent with the 'polluted paradise hypothesis' (Walter & Ugelow, 1979). Industrial structure has a significant positive effect on CE. The secondary and tertiary industries are strongly dependent on fossil fuels in China, and CE would increase with the upgrading of industry. Energy consumption has a significant positive effect on CE. Fossil fuels accounts for more than 95% of China's energy consumption, the more the energy consumption, the greater the CE.

5.3. Endogenous test

Considering the possible two-way causal relationship between GF and CE, and missing variables will lead to the endogeneity of the equation, resulting in the deviation of the regression coefficients. However, due to the lack of instrumental variables and so

Table 4. Regression results with SGMM model.

Variables	(1) CEI	(2) CEPC	(3) CEI	(4) CEPC	(5) CEI	(6) CEPC
CEI (−1)	0.19***		−0.13		−0.12	
	(9.59)		(−1.51)		(−1.51)	
CEPC (−1)		0.39***		−0.01		−0.01
		(29.96)		(−0.17)		(−0.14)
GFI	−0.15***	−0.19***	−0.08***	−0.20***		
	(−4.22)	(−7.26)	(−4.39)	(−9.68)		
GFI (−1)					−0.07***	−0.18***
					(−3.38)	(−12.11)
Control	No	No	Yes	Yes	Yes	Yes
Province	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Sargan	1.00	1.00	1.00	1.00	1.00	1.00
AR(2)	0.14	0.15	0.33	0.10	0.32	0.22
Observations	480	480	480	480	480	480

Note: Sargan value is the p value of constraint test for over identification of instrumental variables, and AR (2) is the p value of Arellano bond second-order sequence correlation test for residuals.
Source: Author's calculated.

on, existing studies paid little attention to the endogeneity of GF (Meo & Abd Karim, 2022). We use the system generalized method of moments (SGMM), proposed by Blundell & Bond (1998), to eliminate the endogeneity of the model. We select the first-order lag of the dependent variable as the explanatory variable based on Hendry's modelling method from general to special (Hendry & krolzig, 2001).

As shown in Table 4, the results show that the values of AR (2) test and Sargan test are greater than 0.1, which indicates that the empirical results are effective. The first-order lag term of both CEI and CEPC have significant positive effects on the current period, indicating that the last period of CE would have positive effects on current period. A possible reason for this is that CE have the path dependence, which is difficult to change in a short time, so there is a strong time-lag effects. Additionally, the coefficients of GFI on CEI and CEPC are −0.08 and −0.20 respectively, which are significant at the level of 1%, suggesting that GFD can still reduce CE in consideration of endogeneity. The regression coefficients between the first-order lag index and CEI and CEPC are −0.07 and −0.18 respectively, which are significant at the 1% level, indicating that considering the endogeneity, the time-lag effects of GF to mitigate CE is still valid.

5.4. Policy effects

In 2007, the China Banking Regulatory Commission (CBRC) established the 'Guiding Opinions on the Credit Work for Energy Conservation and Emission Reduction'. These guidelines instruct banks to restrict or stop lending to 'Two-high & one overcapacity' industries[4] and to implement credit classification management according to the environmental impact of projects. In 2012, CBRC further issued the 'Green Credit Guidelines', which institutionalised the binding of China's GFP and enterprises' environmental performance, put forward clear requirements for banks to carry out green credit policy. Considering that GFP may affect the effect of GF on CE, we classified the samples into three categories (i.e. 2003–2007, 2008–2012 and 2013–2019) to examine the CE-reduction effects of GF before and after enactment of GFP.

Table 5. Green finance development (GFD) and carbon emissions (CE): policy effects.

	2003–2007		2008–2012		2013–2019	
Variables	(1) CEI	(2) CEPC	(3) CEI	(4) CEPC	(5) CEI	(6) CEPC
CEI (−1)	0.52***		1.34***		0.40*	
	(6.17)		(10.97)		(1.93)	
CEPC (−1)		−0.07		−0.04		−0.33*
		(−0.50)		(−0.23)		(−1.77)
GFI	−0.02	0.04	−0.04*	−0.14	−0.12***	−0.15*
	(−0.75)	(0.55)	(−1.79)	(−1.56)	(−3.47)	(−1.76)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Province	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Sargan	0.16	0.46	0.11	0.34	0.61	0.23
AR (2)	0.83	0.60	0.27	0.89	0.37	0.27
Observations	120	120	120	120	180	180

Source: Author's calculated.

As shown in Table 5, the coefficients of GFI on CEI and CEPC are −0.02 and 0.04, respectively, which are not significant in 2003-2007. GFI has a significant negative effect on CEI at the magnitude of −0.04 and has an insignificant effect on CEPC in 2008-2012. Implying that the first official launch of GFP in 2007 has an effective stimulation on alleviation of CE at some extent. During the period of 2013-2019, the coefficients of CEI and CEPC are −0.12 and −0.15, respectively, both significant, which further indicates that the mitigation of CE enhanced after the second round of GFP launched in 2012. The implement of GFP could strengthen the environmental responsibility of financial institutions in following two ways. On the one hand, GFP will inhibit financial institutions from offering fewer loans to high-emission enterprises, thus forcing them to scale down or even withdraw from production and decrease CE. On the other hand, GFP will also guide financial institutions to ease the liquidity constraints of low-emission enterprises and facilitate them to invest more in R&D of low-carbon technologies and produce more green products (Xin et al., 2022). Additionally, GF policy implemented in 2012 performed better in comparison with the policy launched in 2007. Our findings are consistent with Yu et al. (2021) which also focuses on the policy effects of GF on green innovation.

5.5. Moderating effects

Based on the Equations (16) and (17) in section 3, we set follow empirical model to examine the moderating role of ER.

$$CE_i = \beta_0 + \beta_1 GFI + \beta_2 ER_j + \beta_3 (GFI \times ER_j) + \beta_4 Cons + \gamma_0 \tag{19}$$

Where, $i = 1, 2$ represent CEI and CEPC, respectively. $j = 1, 2, 3, 4$ represent ER, AR, MR, and PR, respectively. β_0 is constant term, β_1 、β_2 、β_3 、β_4 are coefficients, *Cons* are control variables, γ_0 is error term.

In Table 6, Models (1) and (2) represent the regression results of ER. GFI and ER have significant negative effects while their cross term has significant positive effects on the two proxy variables of CE, indicating that ER positively moderate the effect of GF on CE. For one thing, compliance cost will surpass profit for high-emission

Table 6. Green finance development (GFD) and carbon emissions (CE): moderating effects.

Variables	(1) CEI	(2) CEPC	(3) CEI	(4) CEPC	(5) CEI	(6) CEPC	(7) CEI	(8) CEPC
GFI	−0.73***	−2.15***	−0.51***	−1.28***	−0.06***	−0.20***	−0.56***	−1.49***
	(−5.90)	(−4.23)	(−6.55)	(−10.76)	(−5.42)	(−4.32)	(−11.11)	(−6.85)
ER	−0.10***	−0.18***						
	(−4.18)	(−3.37)						
ER*GFI	1.21***	3.59***						
	(5.44)	(4.07)						
AR			−0.01***	−0.03***				
			(−4.11)	(−4.61)				
AR*GFI			0.11***	0.28***				
			(5.01)	(8.61)				
MR					$-7.36e^{-3}$*	$-8.56e^{-3}$*		
					(−2.02)	(−1.85)		
MR *GFI					−0.02	0.02		
					(−0.79)	(0.53)		
PR							−0.01***	−0.01***
							(−8.74)	(−7.74)
PR *GFI							0.07***	0.20***
							(11.14)	(6.36)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
R^2	0.56	0.71	0.58	0.68	0.61	0.69	0.58	0.69
Observations	390	390	510	510	510	510	390	390

Source: Author's calculated.

enterprises with stricter ER. Consequently, they will try to give up traditional high-emission production model and increase investment in low-carbon technology innovation with the support of GF. For another, ER can directly act as a persistent commitment from authority for investors, which facilitates the capital flows to low-carbon technological innovation and cleaner production fields from financial sector (Steckel & Jakob, 2018). Additionally, ER could also impede enterprises from seizing GF funds by merely adopting terminal governance or greenwashing.

Furthermore, Models (3) to (8) show the results of moderating effect test of AR, MR, and PR, respectively. Results indicate that both AR and PR have moderating effects on the relationship between GF and CE, while the moderating effect of MR is not significant. AR are based on laws and regulations with mandatory binding force for both financial institutions and enterprises while PR will arouse environmental protection consciousness of the whole society through mass media and force the government to take actions reversely (Xu et al., 2022; Yang et al., 2022). Therefore, both of them play the moderating role between GF and CE. However, for high-emission enterprises, current penalty standard in China is too low to let compliance costs to outweigh profits, they would like to pay fines rather than change existing production mode (Wang, 2016). At the same time, market-based subsidies are inadequate and fail to promote the R&D and utilisation of low-carbon technologies. Additionally, local government may indulge pollution enterprises in pursuit of short-term economic growth goals, thereby giving up enforcing MR strictly (Ren et al., 2021; Wesseh & Lin, 2018). Above all, MR does not have a moderating effect on CE-reduction effects of GF. The heterogeneous moderating effects of different ER tools has been neglected in previous literature (Khan et al., 2019; Liu et al., 2021).

Table 7. Robustness checks using the alternative dependent variable.

Variables	(1) CEI	(2) CEPC	(3) CEI	(4) CEPC	(5) CEI	(6) CEPC
GFI	−0.02**	−0.10**	−0.10***	−0.11***	−0.57***	−1.74***
	(−2.58)	(−3.10)	(−3.21)	(−6.56)	(−5.34)	(3.81)
CEI (−1)			−0.12***			
			(−7.43)			
CEPC (−1)				−0.02**		
				(−2.15)		
GFI (−1)			−0.14***	−0.31***		
			(−3.76)	(−7.68)		
ER					−0.02**	−0.02**
					(−3.61)	(−2.56)
ER*GFI					0.71***	2.41***
					(3.81)	(5.09)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Province	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Time	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Sargan			1.00	1.00		
AR(2)			0.56	0.23		
R^2	0.53	0.62			0.58	0.68
Observations	360	360	330	330	360	360

Source: Author's calculated.

5.6. Robustness checks

In this study, alternative dependent variables are selected to conduct the robustness tests. There are mainly two alternative ways to measure GF, i.e. structured data analysis and text data analysis. This section tries to use text analysis method to construct the GFI to replace the existing independent variables. Drawing on the research of Askitas & Zimmermann (2009), we constructed a text index based on the number of press releases, in which we searched 'green finance' on the government website of the People's Republic of China. Then, we chose the latest top 100 news as the initial thesaurus data source, and selected 20 keywords such as 'green', 'finance' and so on. Finally, we searched the news in the way of 'province + keywords' and constructed the 2008–2019 provincial GF panel data. We employed the new index to regress the main sections again and found that the coefficients and significance of the main variables were close to the results in previous sections, suggesting that the empirical analysis result of this paper is robust. (Table 7)

6. Conclusions and policy implications

GFD is of great significance in the mitigation of CE, while the moderating effects of ER should not be neglected. Using provincial panel data in China from 2003-2019, this paper studied the CE-reduction effects of GF and the moderating effects of ER. Our results revealed that GFD does effectively reduce CEI and CEPC in both short and long-terms, and the conclusion is robust in consideration of endogeneity. Moreover, the implementation of GF policies could facilitate the CE reduction of GF. Furthermore, the CE alleviation effects of GF are moderated by AR and PR. However, the moderating effects of MR are not significant at present.

Our findings offer several lessons to financial and environmental policies formulating. Given the long-term effects of GF on CE, it is imperative to maintain the consistent and steady development of GF by providing fiscal subsidies and taxes relief for financial institutions from the perspective of overall development of GF. Additionally, from the aspect of maturity structure of GF instruments, interest subsidies policies should be considered to prompt financial institutions to design and provide long-term products such as over five-year green bonds and loans for enterprises engaged in low-carbon R&D and production, thus meeting their financing maturity needs.

Moreover, attention should also be paid to facilitating the legislation of GF since the CE-alleviation effects of GF enhanced after the implementation of green policies. On the one hand, the enactment of GFP should instruct financial institutions to further increase the financing costs of high-emission enterprises at a large degree, even forbid those enterprises to obtain money from financial system. On the other hand, GFP should guide financial institutions to undertake more environmental and social responsibility and provide financial support for low-emission enterprises.

Additionally, as one of the most important ER, the role of MR should be enhanced. First, it is necessary to significantly increase the pollution tax, especially for high-emission enterprises, thereby reducing CE effectively. Second, expanding the scope and regions of CE rights trading and establishing a comprehensive trading network and system should also be considered. Third, governments at all levels should provide subsidies to encourage enterprises to adopt low-carbon technologies and the central government should incorporate environmental performance into the assessment targets of local governments.

Finally, the synergy between ER and GF is also of great significance. Environmental protection administrations should punish enterprises that attempt to seize GF funds by merely adopting terminal governance or greenwashing; measures like fines and withdrawal loans should be taken into consideration. At the same time, the formulation and implementation of ER should lead enterprises to promote low-carbon technologies and alleviate the liquidity constraints of environmental protection enterprises through low-carbon technology certification.

Notes

1. https://www.climatewatchdata.org/ghgemissions?breakBy=gas&chartType=percentage&end_year=2019&gases=all-ghg&sectors=total-including-lucf&start_year=1990
2. http://olap.epsnet.com.cn/auth/platform.html?sid=6017DD05A9ED3F7851A85349276A6622_ipv484113472&cubeId=1171
3. We define the environmental responsibility decided by financial rules as the "environmentally responsibility of financial institutions" to differentiate it from ER, mentioned in Section 2.2.
4. "Two-high" industries are high pollution and high energy intensive, and "one overcapacity" industry is overcapacity.

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