



Research article

The impact of China's green finance policy on pollution control: A quantitative analysis of policy texts

Yiguo Chen^a, Peng Luo^{b,*}, Hsin-pei Hsueh^b

^a Research Institute for Dual Circulation Development of the Greater Bay Area, Guangdong University of Finance & Economics, Guangzhou, 510320, China

^b School of Finance, Hubei University of Economics, No. 8 Yangqiaohu Road, Jiang-Xia District, Wuhan 430205, China

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ABSTRACT

In recent years, China has successively introduced green finance policies with continuously strengthened support, and the policy effects have been widely concerned. This paper constructs a theoretical analysis model by incorporating environmental resources into the Cobb-Douglas production function, and deduces that under the local equilibrium state, green finance policies contribute to reducing the pollution intensity of enterprise emissions. In the empirical examination section, this paper establishes a green finance policy intensity index using text analysis, and conducts empirical analysis based on provincial panel data from 2009 to 2019. The study finds that green finance policies help reduce the intensity of industrial pollution emissions, and there exists a synergistic effect between green finance policies and environmental regulations. Further examination reveals that in regions with higher levels of financial development, the pollution control effect of green finance policies is better, and the synergistic effect between green finance policies and environmental regulations is also stronger. Robustness tests also support the above conclusions. Based on this, the green finance policies implemented by the Chinese government have achieved good environmental governance effects and should continue to be implemented and improved. This also provides a model choice for other countries to explore pollution control methods.

1. Introduction

Since the industrial revolution in the 18th century, humanity has extensively burned fossil fuels, releasing substantial amounts of greenhouse gases like carbon dioxide into the atmosphere, which has intensified the greenhouse effect and led to a continuous rise in global temperatures. Climate change has resulted in abnormal global weather patterns, triggering extreme natural disasters such as hurricanes, wildfires, floods, and droughts, posing severe threats and damages to global economic development, food security, human health, and ecosystems. Faced with increasingly severe environmental issues, the world urgently needs to break free from the constraints of resource and environment under the existing growth path and seek new economic growth points. Finance is the core of the modern economy, and green finance has begun to play a significant role in advancing the green and low-carbon transformation of the economic structure, assisting in ecological and environmental protection, and preventing and mitigating climate change risks. In 1980, the United States enacted the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), clarifying

the traceability and joint liability of environmental responsibilities and strengthening the environmental pollution liabilities that banks should bear when lending. In the 1990s, the United Nations Environment Programme (UNEP) formulated guiding documents for the environmental responsibilities of financial institutions such as banks and insurance companies, marking the systematic implementation of environmental management systems by international financial institutions. Under the guidance of green finance policies, institutions such as Citibank, Barclays, and ABN AMRO proposed the "Equator Principles". The Climate Bonds Initiative (CBI) and the International Capital Market Association (ICMA) successively released the Climate Bond Standard (CBS) and the Green Bond Principles (GBP), providing norms and standards for the development of international green credit and green bonds. In 2006, the United Nations issued the Principles for Responsible Investment (PRI), proposing that financial institutions should consider the impact on surrounding societies and the environment when extending credit. In 2013, during the Green Finance Hearing in the British Congress, green finance was defined as financial activities or investment phenomena that protect natural resources, reduce carbon

* Corresponding author.

E-mail address: luop_hbue@163.com (P. Luo).

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emissions, enhance energy efficiency, and address climate change. During the 2016 G20 Hangzhou Summit, China and the UK jointly released the first G20 Green Finance Synthesis Report. Since then, the G20 Summit has annually published green finance development reports, primarily identifying obstacles to sustainable finance development and proposing corresponding solutions.

Meanwhile, China has also started building a green financial system to promote the green transformation of its economy. The earliest step was in 1995 when the People's Bank of China issued the "Notice on Implementing Credit Policies and Strengthening Environmental Protection Work," which was the first time that the credit work of financial institutions was combined with environmental protection, incorporating environmental protection and pollution prevention into bank credit decision-making factors. In November 2007, the China Banking Regulatory Commission issued the "Guiding Opinions on Energy Conservation and Emission Reduction Credit Work," advocating that financial institutions respond to the national energy conservation and emission reduction strategy, reduce loans to "high energy consumption and high pollution projects," and meet the loan demands of "energy-saving and environmental protection projects." In February 2012, the China Banking Regulatory Commission issued the "Green Credit Guidelines," proposing to improve relevant credit management systems, clarify the support direction and key areas of green credit, and promote the transformation of economic development patterns and economic structural adjustment. Guided by green finance policies, financial institutions represented by Industrial Bank actively promoted the development of green finance business and announced the adoption of the "Equator Principles" in 2008, becoming the first Equator Bank in China. During this period, green insurance and carbon market policies also began to take shape. In 2007, the State Environmental Protection Administration and the China Insurance Regulatory Commission issued the "Guiding Opinions on Environmental Pollution Liability Insurance Work," proposing to accelerate the establishment of an environmental pollution liability insurance system and further improve China's environmental pollution risk management system. In 2011, the National Development and Reform Commission launched carbon emissions trading pilots in seven provinces and cities, including Beijing, Tianjin, and Shanghai, covering nearly 3000 key emission units in various industries such as electricity, cement, and steel. In July 2021, the national carbon emissions trading market opened. In September 2015, the CPC Central Committee and the State Council issued the "Overall Plan for Reforming the Ecological Civilization System," explicitly proposing the establishment of an overall framework for a green financial system and the development of green financial products and service systems. In December 2015, the People's Bank of China and the National Development and Reform Commission successively issued the "Green Bond Supported Project Directory" and the "Green Bond Issuance Guidelines," clarifying the norms and standards for green bond issuance. In August 2016, the People's Bank of China, the Ministry of Finance, and other seven ministries and commissions formulated the "Guiding Opinions on Building a Green Financial System," showcasing China's green financial system framework to the world. In September 2020, President Xi Jinping announced at the 75th Session of the United Nations General Assembly that China aims to achieve carbon peaking by 2030 and carbon neutrality by 2060, posing higher and clearer requirements for green finance development to assist ecological civilization construction and high-quality economic development (He and Cheng, 2022).

China's green finance has achieved remarkable achievements and has become the world's largest green credit market and the second-largest green bond market. According to a report released by the People's Bank of China, by the end of 2023, the balance of green loans in both domestic and foreign currencies was 30.08 trillion yuan. Among them, loans to projects with direct and indirect carbon emission reduction benefits were respectively 10.43 trillion RMB and 9.81 trillion RMB, accounting for 67.3 % of green loans in total. According to Wind data, in 2023, China issued 802 green bonds with a total issuance

amount of 1.11805 trillion RMB.

In theory, the supply of green finance funds can, on the one hand, alleviate the financing constraints of enterprises in environmental protection, new energy, and new materials, increase research and development investment, and provide more low-carbon products or services. On the other hand, it will reduce the supply of funds to high-pollution and high-emission enterprises, forcing them to undergo technological transformation and upgrading or reduce production scale. Both aspects may reduce carbon emissions. Many empirical studies targeting the market development indicators of green finance have also confirmed the above effects. However, carbon emissions and pollution emissions exhibit severe externalities, and market failures caused by externalities are difficult to resolve through pure market means, necessitating government intervention. To this end, Chinese governments at all levels have issued the most numerous, most complete, and clearest policy documents to promote the development of green finance, becoming an important model for government-led environmental pollution control (Huang et al., 2023). Therefore, quantitatively measuring China's green finance policies and analyzing their impact on the ecological environment have important policy implications.

2. Literature review

Green finance policies refer to a series of institutional arrangements formulated by government departments for financial institutions and enterprises regarding financing conditions, financing processes, and incentive measures (Chen, 2017). Due to the positive externalities of green finance that are difficult to internalize, the long return period on green finance project investments, and issues such as asymmetric green information, financial institutions lack enthusiasm for developing green finance businesses. Correcting market failures requires the government to establish a comprehensive green finance policy support system (Cai and Zhang, 2014). From a global perspective, governments of developed countries such as the United Kingdom and the United States use legal means to clarify the responsibilities and rights of environmental protection and employ policy tools such as fiscal and tax incentives to support the development of green finance, which has played a role in encouraging green investments and restraining polluting and high-carbon investments in some specific areas (The Joint Research, 2019). Some countries have also established legal systems and law enforcement frameworks to restrict and punish polluting activities, implemented incentive measures such as fiscal subsidies, tax reductions and exemptions, and preferential interest rates for new energy and energy-saving and environmentally friendly technologies and equipment, or promoted the development of green finance by establishing policy banks, such as the UK Green Investment Bank and the German KfW Development Bank (Ma et al., 2017).

Regarding the mechanism of green finance policies, these policies mainly aim to establish a positive incentive mechanism conducive to the development of green finance by improving the return on investment of green projects, enhancing enterprises' awareness of green environmental protection (Ma, 2015), improving information communication mechanisms, perfecting bank-enterprise cooperation mechanisms, and establishing incentive and restraint mechanisms for green credit (Hu et al., 2014). They also aim to reduce investment risks for green enterprises through green finance innovation (Allet and Hudon, 2015), thereby not only providing financing for green investments by governments and enterprises but also supporting the implementation of government regulatory policies and the operation of green financial institutions (Berensmann and Lindenberg, 2016). This achieves a transformation in investment orientation, shifting from a high-energy consumption and high-emission investment-led model to a green and environmentally friendly investment-led model (Volz, 2018). Lv et al (2024) found that the implementation of green finance policies promotes local green technology innovation and industrial structure optimization.

Based on the important role of green finance policies in environmental governance and green development, scholars have conducted research on the effectiveness of related policies. [Su and Lian \(2018\)](#) used the issuance of the "Green Credit Guidelines in 2012 as an event study object and employed a difference-in-differences method to investigate the impact of green finance policies on the investment and financing behavior of heavily polluting industries. They found that the financing constraints faced by heavily polluting enterprises were strengthened, and new investments significantly reduced, thereby achieving a better energy conservation and emission reduction effect. [Tan et al. \(2016\)](#) used China's multi-regional general equilibrium model TermCo2 to study the carbon trading pilot in Hubei Province, exploring the input-output relationship between economic activities and all factors in society. They found that carbon finance policies had a positive impact on the economy and environment of the pilot area, with a significant reduction in carbon emissions and changes in the economic structure characterized by a decrease in investment and an increase in consumption. [Du and Zheng \(2019\)](#) conducted an empirical study on the effectiveness of the carbon emissions trading pilot policy using a difference-in-differences method and found that the growth trend of carbon emissions in pilot areas was significantly lower than that in non-pilot areas. [Hu \(2020\)](#), using panel data from Chinese provinces and cities from 2007 to 2016 and employing a synthetic control method to examine the implementation of Tianjin's carbon trading pilot policy, found that the policy had an inhibitory effect on Tianjin's carbon emissions, but the emission reduction effect was not significant, and it came at the cost of sacrificing some economic development. [Chen et al. \(2021\)](#) found that the central bank's guarantee-type green finance policies significantly stimulated enterprises' green innovation and green transformation. [Lv et al. \(2024\)](#) found through research on panel data from Chinese prefecture-level cities that the implementation of green finance reform and innovation pilot zone policies reduced carbon emission intensity in prefecture-level cities. The latest research shows that green finance and environmental regulation have significant synergistic effects: [Li et al. \(2023\)](#) used a dynamic panel threshold model to analyze the relationship between green finance and total factor carbon productivity (TFCP), with environmental regulation intensity as the threshold variable. The study found that when environmental regulation intensity exceeds a certain threshold, the positive impact of green finance on TFCP becomes more pronounced. In other words, once environmental regulation intensity reaches a certain level, the effectiveness of green finance policies becomes more significant. [Xu et al. \(2024\)](#) utilized panel data from 30 provinces in China between 2012 and 2021 to construct a green finance index. They analyzed the spatial characteristics of green finance development and carbon emissions and used a dynamic spatial Durbin model to explore the impact of green finance on reducing carbon emissions, its spatial spillover effects, and the underlying mechanisms. The study found that green finance significantly reduces carbon emissions, and its spatial spillover effect can effectively reduce carbon emissions in neighboring regions.

In summary, green finance policies have achieved good results in energy conservation and emission reduction. However, existing research often focuses on the implementation of specific policies, leading to an overestimation of policy effects. As we all know, the practice of green finance policies in China has a distinct "top-down" characteristic, meaning that local governments introduce specific implementation measures based on the central government's top-level design, and often multiple local departments jointly introduce multiple measures. Therefore, energy conservation and emission reduction are also the results of the combined effects of many policies. Through a review, we have found that Chinese governments at all levels have issued numerous, comprehensive, and targeted policy documents to promote the development of green finance, and there are significant regional differences, with some provincial and municipal governments not issuing any policies. Local governments have varying levels of emphasis on green finance

development, which may lead to differential impacts on the regional ecological environment, providing a quasi-natural experimental environment for studying policy intensity.

Policy text analysis starts from the content and characteristics of policy documents themselves and conducts quantitative analysis on policy texts, which has been widely used by scholars in recent years. [Libecap \(1978\)](#) was the first to use the Legal Change Index to conduct a quantitative analysis of various legal policy texts related to mineral rights in Nevada, USA. Later, [Daugbjerg et al. \(2009\)](#) studied the effectiveness of 27 sports promotion policies in the UK from eight dimensions: responsible departments, implementation plans, legal status, target groups, policy objectives, time planning, budget, evaluation, and feedback, expanding the ideas for quantitative research on policy texts. [Murphy et al. \(2012\)](#), based on the perspective of policy tools, evaluated energy conservation policies for private residences in the Netherlands in terms of energy certification, housing contracts, economic policies, information policies, building regulations, and other aspects. [Peng J. et al.](#) conducted a text analysis of technological innovation policies from three dimensions: policy intensity, policy measures, and policy objectives, and found that the synergistic effect between technological innovation policies can promote technological capability enhancement ([Peng et al., 2008](#)). [Mi and Yang \(2017\)](#) conducted a quantitative analysis of China's residential energy conservation guidance policies from four dimensions: policy intensity, policy objectives, policy measures, and policy feedback. Policy text analysis has also become an ideal method for green finance policy analysis.

This paper adopts the policy text analysis method to quantitatively measure green finance policies in various provinces and cities in China and analyzes the impact of green finance policies on the ecological environment. Compared with existing literature, the possible academic innovations of this paper are mainly as follows: (1) A policy text analysis method is adopted, which can quantitatively measure green finance policies. Existing research methods often use 1 (or 0) to indicate the presence (or absence) of a policy. Text analysis methods use continuous numerical values to represent the presence or absence of a policy and its intensity. (2) Empirical testing of the effectiveness of green finance in reducing industrial pollution emission intensity, as well as the synergistic environmental governance effects of green finance and environmental regulations. (3) The research in this paper provides empirical evidence for evaluating the effectiveness of green finance policies, contributing to improving the existing green finance development system.

3. Introduction to the index of green finance policy intensity

We use keywords such as green finance, green credit, and carbon finance to conduct extensive searches on the websites of various ministries and committees under the State Council, provincial-level government websites, databases such as Peking University Law Treasure, Wanfang Data, and various publications related to green finance. A total of 874 policy documents related to green finance were obtained, including notices, opinions, guidelines, announcements, summaries, plans, and government work reports. Subsequently, the green finance research team was divided into three small groups, consisting of three experts from commercial banks' green credit departments and three researchers from universities specializing in green finance. These groups carefully studied the aforementioned policy documents and identified 263 localized policy documents based on the title, issuing organization, and content of the documents. To evaluate the policies, this paper applies a three-dimensional scoring system that assesses policy strength, measures, and objectives. In contrast to existing literature that assigns values to policy dimensions, this paper considers that green finance policies are composed of administrative regulations, local regulations, and departmental rules, and the policy text demonstrates strict writing and concise language characteristics. The frequency and intensity of expressions related to green finance products and development in policy

Table 1
Assessment criteria for the strength of regional green finance policies.

Dimension	score	Scoring rules
Policy intensity (PD)	5–6	6 is assigned to documents issued by the General Office of the State Council. Documents issued by central government ministries and commissions are scored starting at 5, and for every additional ministry or commission co-published, the score increases by 0.1.
	4–5	4 is assigned to documents issued solely by the provincial people's government or the provincial party committee office. If these two departments jointly issue the document, a score of 5 is awarded.
	3–4	3 is assigned to documents issued by the environmental protection department, local financial regulatory agencies or government departments. An additional 0.2 points will be added for each additional local financial regulatory agency that co-publishes the document with the department, and an additional 0.1 points will be added for each additional agency that co-publishes the document with the department.
	2–3	2 is assigned for documents issued solely by local financial regulatory agencies. An additional 0.2 points will be added for each additional agency that co-publishes the document with the department.
	1–2	1 is assigned for documents issued by local government departments (excluding financial regulatory agencies) alone. An additional 0.1 points will be added for each additional agency that co-publishes the document with the department.
Policy measures (PM)	5–6	Utilizing comprehensive incentive measures through finance, taxation and financial policies to develop green finance, with clear responsible units and supervision and feedback mechanisms in place. For every additional measure taken, the score increases by 0.1, and for each measure that has clear responsible units, another 0.1 is added, as well as another 0.1 for each measure that has supervision and feedback mechanisms in place.
	4–5	To promote the development of green finance through measures such as finance, taxation and other policies, with a clear system of responsible units and department assessments in place. For each additional measure taken, the score increases by 0.2, and for each measure that has responsible units or assessments in place, another 0.1 is added.
	3–4	Promoting the development of green finance products, strictly controlling financing for polluting industries, and establishing communication and disclosure systems for environmental information, support systems for green lists, etc. For each additional measure taken, the score increases by 0.1.
	2–3	Encouraging and supporting green financial services for environmental protection and low-carbon industries, and restricting and controlling financial support for polluting industries. For each additional related statement, the score increases by 0.1.
Policy objectives (PE)	1–2	Only mentioning the development of green finance without specific supporting measures. For each additional statement, the score increases by 0.1.
	5–6	Based on the content in the range of 4–5 points, if there are additional statements such as "Annual average growth rate of green credit is X%; Annual average decline rate of credit in 'two highs and one remaining' industries is Y%", the score increases by 0.1 for each additional statement.
	4–5	Based on the content in the range of 3–4 points, if there are specific government agencies or department leaders responsible for division of labor, the score increases by 0.1 for each additional government agency or leadership department mentioned.
	3–4	Policy support for green finance talents; specific goals to strengthen green financial innovation and improve green financial infrastructure. The score increases by 0.2 for each additional specific goal mentioned.
	2–3	Propose the construction goals of sub-markets for green credit, insurance, securities, etc. The score increases by 0.1 for each additional sub-market goal mentioned. It is required to establish a green finance department in financial institutions, with an additional score of 0.2.
	1–2	Only proposing to support the development of green finance without specific goals. The score increases by 0.1 for each additional expression of this support.

Note: We will include policies released in November and December of the current year in the following year's count (not for the current year). An example of calculating the score based on provincial policy documents: Guidelines for Green Credit Work in Jiangxi Province (Gan Yin Jian Fa [2018] No.5):1. Policy Intensity (PD): This is issued separately by the Jiangxi Banking Regulatory Bureau, with a base score of 4 points. When jointly issued with the Provincial Environmental Protection Department (adding one department), it adds 0.2 points, resulting in a final score of $4 + 0.2 = 4.2$ points. 2. Policy Measures (PM): It proposes to establish a green credit assessment mechanism and an environmental information sharing platform, which meets the 3–4 point standard, with a base score of 3 points. Each measure adds 0.1 points (a total of 2 measures), adding 0.2 points, and clarifies that the responsible unit is the Inclusive Finance Department of the Jiangxi Banking Regulatory Bureau, adding 0.1 points. The final score is $3 + 0.2 + 0.1 = 3.3$ points. 3. Policy Objectives (PE): It requires that the average annual growth rate of green credit should not be less than 10 %, which meets the 5–6 point standard, with a base score of 5 points. The specific quantitative target adds 0.1 points, resulting in a final score of $5 + 0.1 = 5.1$ points. *Comprehensive Score = PD + PM + PE = $4.2 + 3.3 + 5.1 = 12.6$ points.*

statements can reflect the degree of government attention to green finance and its impact on green finance development. Therefore, this paper scores the frequency and intensity of expressions related to green finance products and development according to policy documents (see Table 1 for scoring standards), and then calculates the regional green finance policy intensity index.

To avoid subjectivity resulting in data distortion, the research team first studied the scoring rules for some time, and then randomly selected several policies for each group to independently score and present their justifications and understanding of the policy. If the difference in scores of a policy dimension among the three groups is (the highest score - lowest score) ≥ 0.3 , they will re-evaluate and discuss until a consensus is reached. To ensure the objectivity of the quantification process, the team leader was responsible for overseeing the entire scoring process.

The method of constructing the Green Finance Policy Intensity Index (GFP) is as follows:

$$GFP_{it} = \sum_{j=1}^N (m_{ijt} + b_{ijt})p_{ijt} + \sum_{l=1}^N LGFP_{ilt} \quad (1)$$

Where m_{ijt} and b_{ijt} represent policy measures and policy goals respectively, p_{ijt} represents policy intensity. i represents 30 provincial-level regions except Tibet, j represents green finance policy, and the interval of t is from 2009 to 2019. Meanwhile, considering that cities such as

Huangshi in Hubei and Huzhou in Zhejiang have issued multiple green finance policies,¹ we score the policies of prefecture-level cities according to the method in Table 1, and include them in GE after weighting them according to the proportion of industrial value added of the prefecture-level city to the industrial value added of the entire province. That is, the weighted intensity of green finance policies in prefecture-level cities LGFP is equal to the score of green finance policies in prefecture-level cities multiplied by (industrial value added of the prefecture-level city/industrial value added of the entire province), where GFP_{ilt} represents the intensity of the l th policy issued by the prefecture-level city under the jurisdiction of region i in year t .

Table 2 shows the number of green finance policies and the average intensity score in each region from 2009 to 2019. It can be seen that the intensity of green finance policies in five pilot zones for green finance reform and innovation, such as Guizhou, Zhejiang and Xinjiang, is among the highest. Non-pilot zones such as Guangdong and Beijing also have relatively high intensity of green finance policies. However, in regions such as Guangxi and Yunnan, both the number and intensity of

¹ For example, in the resource-depleted city of Huangshi, industrial pollution was serious in the early stage. In July 2017, with the issuance of the "Workplan for Creating a Pilot Zone for Green Financial Reform and Innovation in Huangshi City", under the guidance of green finance policies, the energy-saving and emission reduction effect of Huangshi City has been significant.

Table 2

Evaluation of the number and intensity of green finance policies in each region.

Region	Number of Policies	Average Score	Ranking	Region	Number of Policies	Average Score	Ranking
Guizhou	18	45.90	1	Ningxia	17	15.44	16
Zhejiang	14	36.96	2	Shandong	4	14.46	17
Xinjiang	8	31.91	3	Anhui	3	14.31	18
Jiangxi	7	31.46	4	Hunan	13	13.73	19
Guangdong	7	28.77	5	Tianjin	7	13.08	20
Beijing	14	27.81	6	Shaanxi	4	12.85	21
Qinghai	2	27.63	7	Chongqing	16	12.30	22
Fujian	15	26.15	8	Henan	4	11.72	23
Gansu	8	24.80	9	Hubei	9	11.18	24
Liaoning	16	23.00	10	Shanxi	14	9.65	25
Hainan	8	19.15	11	Heilongjiang	14	6.43	26
Sichuan	4	17.17	12	Jilin	5	4.67	27
Inner Mongolia	16	16.27	13	Shanghai	1	4.19	28
Hebei	9	16.13	14	Yunnan	2	3.20	29
Jiangsu	4	15.97	15	Guangxi	0	0.00	30

Note: The data in the table show the number of green finance policies and average scores for each region from 2009 to 2019. The scoring method is based on the scoring criteria in Table 1.

green finance policies are relatively weak, indicating that these regions need to strengthen the construction of green finance systems.

4. Theoretical analysis and modeling

4.1. Theoretical understanding

This section constructs a two-sector economic system consisting of government and enterprises to analyze how green finance affects corporate pollution emissions. Based on the Cobb-Douglas production function, enterprises invest in capital (K), labor (L), and environmental resources (E) to maximize profits and form output, but the use of environmental resources such as energy and land produces negative externalities in the form of pollution emissions. The government influences the production and pollution emissions behavior of enterprises through two means: developing green finance and implementing environmental regulations. Green finance can optimize the allocation of green resources; internalize positive externalities of green production, and negative externalities of pollution emissions. Environmental regulations mainly levy environmental protection taxes on pollution emissions, promoting the internalization of negative externalities of pollution emissions. Polluting enterprises face dual constraints of green financing policies and increased pollution costs due to environmental regulations, which negatively affect their goal of profit maximization. Therefore, polluting enterprises need to adjust their production and pollution emissions behavior.

(1) The production behavior of enterprises

Inspired by Tong et al. (2016), the production function of enterprises is set as:

$$\ln PI_{it} = \beta_0 + \beta_1 \ln PI_{it-1} + \beta_2 GFP_{it} + \beta_3 Reg_{it} + Contr_{it} + \varepsilon_{it} \quad (2)$$

Here, $\ln PI_{it} = \beta_0 + \beta_1 \ln PI_{it-1} + \beta_2 GFP_{it} + \beta_3 Reg_{it} + \beta_4 GFP_{it}^* Reg_{it} + Contr_{it} + \varepsilon_{it}$ represents the environmental technology level, A_t represents the total factor productivity, K , L , and E represent the capital, labor, and environmental resources invested by the enterprise in period t . It is assumed that the scale returns of the enterprise are constant, i.e. $(\varepsilon + \varepsilon + UE_{ijt} = E_{ijt}/O_{ijt}) = 1$. The use of environmental resources will generate pollution emissions, and the pollution emission equation of the enterprise is:

$$E_{ijt} \quad (3)$$

The parameter O_{ijt} represents the emission coefficient and UE_{ijt} , which means marginal emissions decrease. $UE_{ijt}^s = [UE_{ijt} - \min(UE_{jt})] /$

$[\max(UE_{jt}) - \min(UE_{jt})]$ indicating that at the same environmental technology level, the use of environmental resources and pollution emissions are proportional. $\max(UE_{jt})$ indicating that at the same level of environmental resource use, the environmental technology level and pollution emissions are inversely proportional.

(2) Allocation of production resources

Green finance policies can promote financial capital to disengage from the polluting industry. Assuming that the financing provided by the financial market is Fin , the evaluation of a company's pollution level by environmental protection agencies is $\min(UE_{jt})$, and the intensity of the green finance policy is GFP , the credit resources that the company can obtain will be $(1 - PI_{it} = \sum_{j=1}^n UE_{jt}^s / n \cdot GFP) \cdot Fin$. This means that the greater the level of pollution of the company, the less credit it can obtain, and the green finance policy can strengthen this effect. Meanwhile, the company also needs to pay environmental protection taxes for its pollution emissions, and the environmental tax rate is $IA = (X_{ij} / \sum_i X_{ij}) (\sum_j X_{ij} / \sum_i \sum_j X_{ij})$, indicating that the higher the environmental regulation intensity (Reg), the greater the environmental tax burden on the company. The profit function of the company can be represented as:

$$\pi_t = pY_t - (rk_t + \omega L_t + \kappa E_t) - vPE_t \quad (4)$$

Where p represents the product price, r , ω and κ respectively represent the prices of capital, labor, and environmental resources. The company's capital investment relies on financing from the financial market. Therefore, the capital investment in period t will be $k_t = (1 - \varphi GFP_t) \cdot Fin$, and the resulting capital stock will be $K_t = k_t + K_{t-1}$, K_{t-1} is the initial level of capital.

The first-order condition of environmental resources and policy intensity in equation (4) yields the production decision of the enterprise.

$$PE = (\gamma pY - \kappa) / \rho v Reg \quad (5)$$

$$\alpha pY = r(1 - \varphi GFP) \cdot Fin \quad (6)$$

Therefore, the pollution intensity (PI) of the enterprise is:

$$PI = \frac{PE}{Y} = \frac{p}{\rho v Reg} \left(\gamma + \frac{\alpha \kappa}{r^* \cdot Fin^* (\varphi GFP - 1)} \right) \quad (7)$$

Considering that the industrial pollution emission intensity in the economic system is always positive, therefore, in the prior setting formula (7) here, $[\gamma + \alpha \kappa / r^* \cdot Fin^* (\varphi GFP - 1)] > 0$. Differentiating formula (7) with respect to Reg and GFP respectively:

$$\frac{\partial PI}{\partial Reg} = -\frac{p}{\rho v Reg^2} \left(\gamma + \frac{\alpha \kappa}{r^* Fin^* (\varphi GFP - 1)} \right) \quad (8)$$

$$\frac{\partial PI}{\partial GFP} = -\frac{\varphi \alpha \kappa p}{\rho v r Reg^* Fin^* (\varphi GFP - 1)^2} \quad (9)$$

It can be concluded that $\partial PI / \partial Reg < 0$ and $\partial PI / \partial GFP < 0$, indicating a negative relationship between environmental regulation intensity (Reg) and green finance policy (GFP) with industrial pollution intensity (PI), and increasing environmental regulation intensity can amplify the effect of green finance policy (GFP) on industrial pollution intensity (PI), forming an environmental synergistic governance effect between the two measures. Financial development (Fin) as an exogenous variable, developed financial markets help amplify the effect of green finance policy (GFP) on industrial pollution intensity (PI). Therefore, this paper proposes two hypotheses:

Hypothesis 1. Green finance policies help reduce pollution intensity, and have a better effect in areas with better financial development.

Hypothesis 2. There is an environmental synergistic governance effect between green finance policies and environmental regulation, and the synergistic effect is better in areas with better financial development.

4.2. Econometric model

To test the impact of China's green finance policy on pollution control, based on the method used by Liu (2017), the following dynamic panel regression model is set up:

$$\ln PI_{it} = \beta_0 + \beta_1 \ln PI_{it-1} + \beta_2 GFP_{it} + \beta_3 Reg_{it} + Contr_{it} + \varepsilon_{it} \quad (10)$$

$$\ln PI_{it} = \beta_0 + \beta_1 \ln PI_{it-1} + \beta_2 GFP_{it} + \beta_3 Reg_{it} + \beta_4 GFP_{it} * Reg_{it} + Contr_{it} + \varepsilon_{it} \quad (11)$$

Where PI represents industrial pollution intensity, GFP represents the intensity of green finance policy, and Reg represents the intensity of environmental regulations. The control variables include industrial agglomeration (IA), industrial structure (IS), foreign direct investment (FDI), financial development (Fin), and economic development level (gdp). i and t represent region and time, and ε is the random error term.

Considering that the industrial pollution intensity may have strong time inertia, the pollution emission in period t is influenced by the previous period $t-1$. Therefore, the lagged one-period dependent variable of PI is used as the explanatory variable. However, using the lagged dependent variable as an explanatory variable can lead to endogeneity issue due to its high correlation with the error term ε . Endogeneity can lead to biased coefficient estimates. Therefore, this paper adopts the second-order system generalized method of moments estimation method (2Sys-GMM) proposed by Arellano and Bover (1995), which introduces difference and level equations in the model and uses the difference lagged terms of the dependent variable and exogenous variables as instrumental variables to obtain estimates with smaller biases. The consistency of GMM estimation depends on the effectiveness of the instrumental variables selected. The Sargan test is used to test the over-identification of instrumental variables, and the null hypothesis is that the instrumental variables are effective. The Arellano-Bond sequential autocorrelation test is used to test the second-order serial correlation problem of residuals (Bond, 2002).

4.3. Variables and its description

Industrial pollution emissions mainly consist of wastewater, waste gas, dust, and solid waste. Following the method of Wang and Liu (2014), industrial sulfur dioxide emission, industrial smoke and dust emission, industrial chemical oxygen demand (COD) emission,

wastewater discharge, and industrial solid waste are used to comprehensively measure industrial pollution emission intensity. The weight distribution of pollutants, such as SO₂, COD, and particulate matter, is based on the equal weighting method, where each pollutant's standardized value has an equal share in the composite index. Specifically, if there are n pollutants, each pollutant has a weight of $1/n$. This method avoids subjective bias and ensures that all pollutants have an equal impact on the overall pollution intensity.

- (1) Calculate the intensity of pollution emissions. $UE_{ijt} = E_{ijt} / O_{ijt}$. Here, E_{ijt} and O_{ijt} represent the pollution emission intensity of the j pollutant and industrial value added in the region i at time t , respectively.
- (2) Standardize Line UE_{ijt} linearly $UE_{ijt}^s = [UE_{ijt} - \min(UE_{jt})] / [\max(UE_{jt}) - \min(UE_{jt})]$. Here $\max(UE_{jt})$ and $\min(UE_{jt})$ represent the maximum and minimum values of the j pollutant emission intensity in the region at time t , respectively.
- (3) Obtain the weighted average of the calculated pollution intensity, that is $PI_{it} = \sum_{j=1}^n UE_{ijt}^s / n$. Among them, n represents the number of pollutants considered. In this study, n includes sulfur dioxide (SO₂), chemical oxygen demand (COD), soot, wastewater and solid waste five kinds of pollutants. Finally, the industrial pollution emission intensity (PI) is obtained.

The green finance policy intensity is obtained by collecting green finance policies issued by local governments from 2009 to 2019, and textually quantifying it from three dimensions of policy intensity, policy measures, and policy objectives.

There are significant differences in the measurement methods for environmental regulation intensity in existing research, mainly using indicators such as pollution control investment, pollutant discharge fee revenue, number of environmental administrative regulations, and number of environmental administrative penalty cases to measure environmental regulation intensity. Considering that the research object of this study is industrial pollutant emissions intensity, it is more appropriate to use environmental regulation measures in the industrial sector. Following the practice of You and Wang (2016), the proportion of industrial pollution control investment completed to industrial value-added is used to measure environmental regulation intensity.

We also select the following indicators as control variables: ① Industrial Agglomeration (IA) using the location entropy to measure industrial agglomeration, the expression is: $IA = (X_{ij} / \sum_i X_{ij}) (\sum_j X_{ij} / \sum_i \sum_j X_{ij})$, where i represents the industry ($i = 1, 2, 3$), j represents the region, and X_{ij} represents the output value of industry i in region j . ② Foreign Direct Investment (FDI) using the proportion of FDI denominated to GDP. FDI can bring more advanced production technologies and enforce stricter environmental standards in host countries, which contributes to improving environmental pollution. ③ Financial Development (Fin) using the ratio of year-end loan balances to GDP. The total financial development index is measured by a composite indicator of direct and indirect financing. Direct financing is represented by the ratio of stock market financing to GDP. Indirect financing is indicated by the ratio of year-end bank loan balances to GDP. The total financial development index is the sum of these two, calculated as: $Fin = (\text{stock market financing} + \text{bank loan balance}) / \text{GDP}$. ④ Economic Development Level (gdp) measured by taking the logarithm of per capita GDP. Bergstrom et al. (1990) argue that the degree of environmental pollution is determined by people's willingness to pay for a clean environment, and residents in high-income areas generally have stronger willingness and higher access to information related to environmental pollution and hazards. Therefore, their demand for a clean environment is increased. ⑤ Industrial Structure (IS) using the proportion of the second industry to GDP. Areas with a higher proportion of the second industry often have more basic industrial enterprises in chemicals, cement, and smelting, which can

increase industrial pollution emissions intensity.

4.4. Data

The main data sources of this article are "China Statistical Yearbook", "China Environmental Statistical Yearbook" and "China Science and Technology Statistical Yearbook". The intensity of green finance policies was obtained through retrieval from various levels of government websites, PKU Law Information, and Wanfang Database, and then quantified. Finally, panel data of 30 provincial-level regions from 2009 to 2019 (excluding Tibet) were formed. Table 3 presents the descriptive statistics of each variable.

4.5. Regression results of the baseline model

This section empirically tests causal relationship using GMM model (Table 4).² The Sargan statistic of each regression show that the instrumental variables are properly set and the AR (2) test indicates there is no residual second-order serial correlation, which proves that the GMM regression model adopted in this article is reasonable. The regression coefficients of the green finance policy intensity (GFP) in columns (1)–(5) are all significantly negative, indicating that the green finance policy intensity can reduce the intensity of industrial pollution emissions. In column (2), the impact of environmental regulations (Reg) on the intensity of industrial pollution emissions is significantly negative, which is consistent with the research conclusions of Laplante and Rilstone (1996). Columns (3)–(5) incorporate the interaction terms of environmental regulations (Reg) and green finance policy intensity (GFP) into the regression model, and the regression coefficients of the interaction terms are all significantly negative, indicating that the two policies can produce a synergistic effect on pollution control.

The synergistic effect arises from several factors. Firstly, stringent environmental regulations escalate the investment risk associated with heavily polluting sectors, while green finance policies amplify the financing restrictions on these same industries. This dual pressure creates a "crowding-out effect," effectively restricting capital flow into high-polluting industries. Concurrently, green finance measures alleviate financing barriers for environmentally friendly sectors, thereby channeling the capital displaced from polluting industries, under regulatory pressure, towards green and sustainable initiatives. Consequently, this coordinated action between regulations and finance not only curbs investments in pollution-intensive sectors but also bolsters the green environmental protection industry, collectively driving down industrial pollution emissions.

4.6. Heterogeneity test of financial development

The important role of green finance policy is to guide financial capital to invest in the green industry. Therefore, the development of green finance needs to rely on developed financial markets. In order to verify the moderating effect of financial development, we followed the approach of Su and Lian (2018) and calculated the average financial development level of each province and city from 2009 to 2019. Using the median of financial development level as the benchmark, the sample is divided into financially developed areas and financially underdeveloped areas for heterogeneity regression.

Table 5 reports the heterogeneity regression results of financial development level. The regression results of the green finance policy intensity (GFP) in financially underdeveloped areas are significantly negative in columns (1) to (3). However, in column (3), the regression coefficient of the interaction term between green finance policy intensity and environmental regulations is not significant. This suggests

that the environmental governance synergy effect between green finance policy and environmental regulations in financially underdeveloped areas does not exist. The possible reason may be that the capital allocation function in underdeveloped financial markets is incomplete, making it difficult to transform high-polluting industry capital "crowded out" by environmental regulations into green investment. In addition, the ability to analyze and utilize enterprise environmental information in financial markets is suppressed.

In columns (4) to (6), the impacts of green finance policy intensity (GFP) and the interaction term between policy intensity (GFP) and environmental regulations (Reg) on pollution emissions intensity in financially developed areas are significantly negative. Compared with the regression coefficients in financially underdeveloped areas using the regression results of columns (3) and (6) as benchmarks, it was found that the absolute values of the regression coefficients of green finance policy intensity and the interaction term between policy intensity and environmental regulations in financially developed areas are higher than those in financially underdeveloped areas. This indicates that the green finance policies in financially developed areas have better effects in reducing industrial pollution emissions intensity because they can guide financial capital to invest in the green industry. Developed financial markets can create more green investment projects, thereby achieving better industrial pollution control effects. At the same time, the financial market in financially developed areas can better absorb the spillover capital of high-polluting industries under environmental regulations, making the environmental governance synergy effect of green finance policy and environmental regulations more significant.

5. Robustness test

5.1. Using lagged values of core explanatory variables

Due to the fact that GMM regression can only eliminate the endogeneity caused by lagged dependent variables as independent variables, for areas with severe pollution emissions, the government has a stronger motivation to issue green finance policies and increase policy intensity, thus forming endogeneity of bidirectional causal relationship between green finance policies intensity and pollution emission intensity. In this paper, the lagged variable L.GFP is included in the model instead of the current value for robust regression. Since the dependent variable PI does not have an impact on the lagged independent variable, it can better control the endogeneity caused by the bidirectional causal relationship, and the regression results are shown in Table 6.

The robustness test applies GMM regression method, and examines the impact of the lagged Green Finance Policy Index (L.GFP), Environmental Regulation (Reg), and their interaction term on industrial pollution intensity. Table 6 reports the relevant regression results. The regression coefficient of the lagged one-period value of L.GFP is all significantly negative. The interaction terms of lagged Green Finance Policy Index and environmental pollution term in columns (3) to (5) are all significantly negative, indicating that the synergistic effect of pollution control by the two can be established. Which suggest that the Green Finance Policy Index can effectively reduce industrial pollution intensity, and there is a synergistic effect of pollution control between the Green Finance Policy Index and environmental regulation intensity.

Table 7 reports the robust regression results via grouping the sample by financial development. Columns (1) to (3) indicate the effects of the lagged green finance policy intensity (L.GFP) in financially underdeveloped areas, environmental regulation intensity, and the interaction between the two on pollution emission intensity. Using the regression results of column (3) as the baseline, the regression coefficient of the green finance policy intensity (L.GFP) is -0.085 and passes the 1 % significance test, while the regression coefficient of the interaction between the policy intensity and the lagged environmental regulation (L.GFP*Reg) is -0.142 . Columns (4) to (6) indicate the effects of the lagged policy intensity (L.GFP), environmental regulation intensity (Reg), and

² The VIF values were in the range of [2.12, 7.61], indicating that there was no serious multi-collinearity in the model.

Table 3
Summary statistics.

	ln(PI)	GFP	Reg	IA	FDI	Fin	gdp	IS
Mean	−2.182	10.011	0.0037	1.047	0.025	2.494	1.295	0.465
Median	−2.154	4.191	0.0024	1.098	0.019	3.856	1.315	0.477
Sd	1.004	20.853	0.0043	0.176	0.018	0.899	0.548	0.083
Min	−5.284	0	0.0015	0.461	0.0007	0.732	2.476	0.188
Max	−0.311	143.96	0.0233	1.294	0.103	7.302	2.369	0.615
Obs	330	330	330	330	330	330	330	330

Table 4
Baseline model.

	(1) GMM	(2) GMM	(3) GMM	(4) GMM	(5) GMM
L.ln(PI)	0.712*** (12.794)	0.784*** (8.052)	0.696*** (6.320)	0.735*** (8.391)	0.704*** (11.015)
GFP	−0.014*** (−3.235)		−0.012** (−2.439)		−0.011* (−1.746)
Reg		−0.249*** (−7.634)		−0.229*** (−6.806)	−0.209*** (−7.102)
GFP*Reg			−0.418** (−2.167)	−0.418** (−2.167)	−0.316*** (−2.762)
IA	−0.055 (−0.930)	−0.093** (−2.477)	−0.239 (−0.694)	−0.057*** (−3.838)	−0.007** (−2.691)
FDI	−0.732*** (−3.146)	−1.775*** (−6.964)	−0.366*** (−3.868)	−0.808*** (−2.741)	−0.567*** (−2.864)
Fin	−0.062** (−2.437)	−0.018* (−1.881)	−0.008*** (2.816)	−0.048 (−1.508)	−0.012** (−1.985)
gdp	−0.036* (−1.751)	−0.066** (−2.266)	−0.059** (−2.303)	−0.055* (−1.692)	−0.036 (−0.746)
IS	0.402 (1.06)	0.355** (2.373)	0.270* (1.920)	0.271*** (2.997)	0.202** (2.199)
constant	0.198*** (7.997)	0.284*** (8.051)	0.226*** (8.014)	0.528*** (5.262)	0.236*** (7.868)
AR(1)	0.078	0.041	0.024	0.036	0.035
AR(2)	0.323	0.276	0.282	0.283	0.381
Sargan	0.651	0.608	0.922	0.757	1

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

Table 5
Heterogeneity Test results of Financial Development.

	Underdeveloped regions			Developed regions		
	(1)	(2)	(3)	(4)	(5)	(6)
L.ln(PI)	0.847*** (4.580)	0.837*** (5.175)	0.835*** (3.755)	0.749*** (3.923)	0.775*** (2.846)	0.754*** (4.957)
GFP	−0.012** (−2.354)		−0.016** (−2.032)	−0.027*** (−2.753)		−0.023*** (−3.319)
Reg		−0.194** (−2.194)	−0.286* (−1.798)		−0.185*** (−4.978)	−0.187* (−1.788)
GFP*Reg			−0.148 (−0.944)			−0.417** (−2.572)
IA	−0.028* (−1.946)	−0.006** (−2.261)	−0.077** (−2.085)	−0.016 (−0.651)	−0.074* (−1.726)	−0.015 (−0.574)
FDI	−0.594** (−2.114)	−0.578** (−2.556)	−0.654*** (−3.537)	−0.421*** (−3.318)	−0.954*** (−3.563)	−0.418*** (−3.331)
Fin	−0.031*** (−5.051)	−0.012** (−1.924)	−0.029*** (−4.038)	−0.009* (−1.665)	−0.029*** (−4.031)	−0.004 (−0.792)
gdp	−0.022 (−1.339)	−0.035 (−1.322)	−0.032* (−1.692)	−0.036*** (−4.542)	−0.032** (−2.529)	−0.036*** (−4.574)
IS	0.129** (1.989)	0.198* (2.318)	0.091 (1.259)	0.115*** (2.924)	0.098 (1.361)	0.116** (2.319)
constant	0.293* (1.951)	0.232* (1.629)	0.348** (2.447)	0.176** (2.365)	0.349*** (10.432)	0.176*** (7.504)
AR(1)	0.032	0.067	0.026	0.041	0.057	0.082
AR(2)	0.648	0.219	0.596	0.383	0.232	0.462
Sargan	1	0.749	1	0.656	1	1

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

Table 6
Robustness test using lagged values of core explanatory variables.

	(1) GMM	(2) GMM	(3) GMM	(4) GMM	(5) GMM
L.ln(PI)	0.821*** (11.096)	0.696*** (8.982)	0.814*** (6.981)	0.733*** (8.576)	0.742*** (3.795)
L.GFP	−0.015*** (−2.631)		−0.012** (−2.207)		−0.011** (−2.316)
Reg		−0.037** (−2.443)		−0.017* (1.926)	−0.044*** (−3.132)
L.GFP*Reg			−0.112* (−1.716)	−0.119* (−1.906)	−0.263* (−1.674)
IA	−0.315*** (−5.405)	−0.263*** (−4.856)	−0.312*** (−5.318)	−0.186*** (−3.171)	−0.281*** (−4.877)
FDI	−0.674*** (−2.676)	−0.558** (−2.392)	−0.679*** (−2.703)	−0.157 (−0.509)	−0.553** (−2.443)
Fin	−0.003 (−0.447)	−0.008* (−1.684)	−0.003 (0.523)	−0.028*** (−3.822)	−0.004** (−2.306)
gdp	−0.054*** (−3.813)	−0.064** (−2.371)	−0.052 (−0.654)	−0.064*** (−3.332)	−0.059*** (−4.095)
IS	0.538** (2.251)	0.518 (1.416)	0.528* (1.948)	0.466*** (4.477)	0.543*** (5.361)
constant	0.084*** (3.479)	0.028*** (4.117)	0.087*** (3.539)	0.037*** (4.825)	0.043*** (5.632)
AR(1)	0.121	0.066	0.047	0.071	0.059
AR(2)	0.337	0.264	0.148	0.258	0.159
Sargan	0.651	0.608	0.922	0.660	0.742

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

Table 7

Robustness Test: Grouping the sample by financial development.

	Underdeveloped regions			Developed regions		
	(1)	(2)	(3)	(4)	(5)	(6)
L.ln(P1)	0.847*** (4.580)	0.837*** (5.175)	0.835*** (3.755)	0.749*** (3.924)	0.775*** (2.846)	0.754*** (4.958)
L.GFP	−0.127 (−1.354)		−0.085* (−2.032)	−0.302*** (−2.753)		−0.116*** (−3.319)
Reg		−0.224** (−2.194)	−0.376 (−1.198)		−0.275*** (−4.978)	−0.323*** (−6.244)
L.GFP*Reg			−0.142* (−1.944)			−0.161** (−2.552)
IA	−0.041* (−1.708)	−0.013 (−1.176)	−0.055*** (−2.846)	−0.088** (−2.397)	−0.076 (−0.829)	−0.092*** (−2.430)
FDI	−0.685* (−1.728)	−0.661 (−0.644)	−0.679 (−0.753)	−0.550** (−2.365)	−0.652* (−1.878)	−0.619*** (−3.827)
Fin	−0.043** (−2.236)	−0.013*** (−2.653)	−0.038*** (−5.542)	−0.006 (−0.906)	−0.043** (−2.215)	−0.002 (−0.881)
gdp	−0.095** (−1.983)	−0.027*** (−3.379)	−0.074* (−1.915)	−0.064*** (−4.320)	−0.093* (−1.945)	−0.084** (−2.411)
IS	0.849 (0.759)	0.151** (2.317)	0.481* (1.615)	0.561*** (5.482)	0.631*** (3.636)	0.623*** (4.359)
constant	0.278* (1.929)	0.121*** (6.133)	0.029** (2.206)	0.036*** (6.693)	0.047*** (4.472)	0.029*** (3.323)
AR(1)	0.032	0.067	0.026	0.041	0.057	0.082
AR(2)	0.296	0.872	0.215	0.749	0.387	0.648
Sargan	0.749	0.58	0.656	1	0.861	1

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

the interaction between the two on pollution emission intensity in financially developed areas, and the regression coefficients of each variable are all significantly negative. Comparing the regression results of columns (3) and (6), the absolute value of the regression coefficient of L.GFP in column 6 is 0.116 which is greater than the absolute value of the regression coefficient of L.GFP in column (3) which is 0.085. The absolute value of the regression coefficient of the interaction term in column (6) is 0.161 which is greater than the absolute value of the regression coefficient in column (3) which is 0.142, indicating once again that green finance policies in financially developed areas, as well as the synergistic effect of green finance policies and environmental regulations, are better.³

5.2. A new explained variable

To further verify the robustness of the regression results in this paper, following the approach of Guo and Yuan (2019), the natural logarithm of industrial sulfur dioxide emissions (SO2) is selected as the measure of industrial pollution emissions. The robustness regression results of the baseline model are presented in Table 8, where no significant changes occur in the regression coefficients, indicating the positive role of green finance policies and environmental regulations in reducing pollution emissions.

Replace the original explanatory variable with industrial sulfur dioxide emissions (SO2) to conduct a heterogeneity test on the financial development. The relevant regression results are presented in Table 9. The significance of the variables remains unchanged, further confirming the pollution reduction effects and synergistic governance effects of green finance policies.

6. Conclusion and policy implication

Green finance policies aim to achieve the goal of reducing pollution emissions and promoting green development by building a comprehensive green finance development system to ensure its sustainable development. To explore whether the green finance policy system can achieve the above goals, this paper collecting 263 provincial and municipal green finance policy documents and using text analysis to construct a green finance policy intensity index from three dimensions - policy strength, policy measures, and policy objectives - this paper

³ Drawing on the approach of taking the logarithm of industrial chemical oxygen demand (COD) per industrial value added as a measure of industrial pollution emissions intensity, as used by Lu Ming and Feng Hao (2014), the coefficients of the variables in the regression did not change significantly in this study. This indicates that the conclusions obtained are reliable. Due to space limitations, the regression results are not displayed in the text.

Table 8

Robustness test via dependent variable substitution.

	(1) GMM	(2) GMM	(3) GMM
L.ln(SO2)	0.885*** (14.153)	0.869*** (5.778)	0.891*** (4.710)
GFP	−0.416** (−2.319)	−0.423** (−2.174)	−0.389* (−1.780)
Reg			−0.648** (−2.511)
GFP*Reg		−0.063** (−2.352)	−0.051* (−1.866)
IA	−0.158*** (−4.529)	−0.167*** (−5.341)	−0.177*** (−5.016)
FDI	−0.228*** (−2.955)	−0.251*** (−2.714)	−0.233** (−2.469)
Fin	−0.037 (−0.419)	−0.032 (−0.536)	−0.034 (−0.657)
gdp	−0.108*** (−3.756)	−0.114*** (−3.182)	−0.097*** (−4.399)
IS	0.047** (2.217)	0.049** (2.334)	0.054** (2.269)
constant	0.184*** (5.217)	0.187*** (4.996)	0.143*** (5.133)
AR(1)	0.185	0.144	0.107
AR(2)	0.451	0.370	0.298
Sargan	0.769	0.837	0.725

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

Table 9

Further robustness test: Grouping the sample by financial development.

	Underdeveloped regions		Developed regions	
	(1)	(2)	(3)	(4)
L.ln (SO2)	0.885*** (4.290)	0.867*** (4.688)	0.780*** (5.727)	0.795*** (5.911)
GFP	−0.008 (−0.854)	−0.010 (−1.127)	−0.017** (−2.311)	−0.015** (−2.359)
Reg		−0.056 (−1.322)		−0.044 (−1.295)
GFP*Reg		−0.005* (−1.317)		−0.003* (−1.404)
IA	−0.038 (−0.658)	−0.032 (−0.730)	−0.128** (−2.297)	−0.105** (−2.293)
FDI	−0.081 (−0.597)	−0.079 (−0.780)	−0.041 (−1.353)	−0.042 (−1.407)
Fin	−0.613** (−2.112)	−0.618** (−2.148)	−0.736* (−1.830)	−0.715** (−2.081)
gdp	−0.158*** (−2.970)	−0.176*** (−3.216)	−0.260*** (−4.320)	−0.214*** (−2.411)
IS	0.316 (0.638)	0.322 (0.630)	0.748 (1.665)	0.753 (1.657)
constant	0.571*** (5.118)	0.582*** (5.123)	0.469*** (6.437)	0.475*** (6.388)
AR(1)	0.157	0.162	0.144	0.185
AR(2)	0.321	0.318	0.550	0.529
Sargan	0.651	0.634	0.748	0.782

Note: ***, **, and * represent significance at the 1 %, 5 %, and 10 % levels respectively, with t-values in parentheses.

investigates the impact of green finance policy intensity on industrial pollution emissions intensity. The study found that: (1) Higher green finance policy intensity indicates that local governments attach more importance to green finance development, which helps to reduce industrial pollution emissions intensity. (2) Green finance policies can guide high-polluting industry capital flows toward green industries, forming an environmental synergistic governance effect between green finance and environmental regulation. (3) Areas with developed financial systems show more significant environmental pollution reduction effects with better environmental synergistic governance effects between green finance and environmental regulation.

The above research findings have rich policy implications. Firstly, to promote the green transformation and development of the economy, it is recommended to continue improving the implementation of green finance policies. The government should use financial and tax incentives, construct green information platforms, and promote public green finance literacy education to encourage social capital to enter green industries such as energy conservation and environmental protection, build a sustainable mechanism for the development of green finance, and delegate policy-making authority for green finance policies to lower levels. Secondly, the coordinated development of traditional finance and green finance should be strengthened by relying on well-developed traditional financial systems, encouraging financial institutions to adopt green finance attributes in traditional financial products, and exploring green finance innovation. Thirdly, the synergistic effect of pollution control between green finance policy and environmental regulation should be fully utilized by establishing an environmental regulation tax collection system that transforms into target subsidies for green finance to maximize social welfare in the environmental economic field. Lastly, Local governments should adjust their green finance policies to enhance pollution reduction effects. Based on the actual local economic development, industrial structure, and environmental quality, they should formulate differentiated green finance policies. For example, in regions with developed industries but severe pollution, financial support for clean energy and energy-saving and emission-reduction projects can be increased. Green finance policies should be integrated with other relevant policies (such as industrial policies and regional development policies) to form a cohesive policy system. This not only improves policy effectiveness but also avoids conflicts and contradictions between policies. Leveraging digital technologies such as big data, cloud computing, and artificial intelligence can enhance the implementation efficiency and precision of green finance policies. For instance, establishing a green finance information platform enables rapid dissemination and sharing of policy information, and utilizing big data analysis technology allows for precise assessment of the environmental performance of enterprises and projects.

CRedit authorship contribution statement

Yiguo Chen: Writing – review & editing, Writing – original draft, Funding acquisition, Conceptualization. **Peng Luo:** Formal analysis, Data curation. **Hsin-pei Hsueh:** Software, Methodology.

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Declaration of competing interest

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

Data availability

Data will be made available on request.

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