

The Impact of Green Financial Development on Environmental Pollution—Evidence from 244 Prefecture-Level Cities in China

Zhuofei Wu^{*}, Yixuan Zhu

Department of International College, Jiangxi University of Finance and Economics University,
Nanchang, China, 330013

^{*} Corresponding Author Email: kch3401924280@163.com

Abstract. Considering the call for "pollution and emission reduction" of China, it's of great significance to explore whether the development of sustainable finance contributes to the improvement of ecological and environmental quality is of great significance. Therefore, based on the panel data of 244 prefecture-level cities in China from 2016 to 2023, this paper uses a two-way fixed effects model (TFE) to empirically examine the influence of green financial development on fine particulate matter (PM_{2.5}) emissions. The research results show that the development of green finance has a promoting effect on PM_{2.5} emissions, indicating a greenwashing phenomenon. This promoting effect remained robust after a set of robustness tests. Heterogeneity analysis shows that the effect of green finance is more evident in less developed regions and central regions.

Keywords: Green Financial Development, Environmental Pollution, Prefecture-Level Cities, Greenwashing.

1. Introduction

With the acceleration of industrialization, air pollution issues have become increasingly severe. In recent years, frequent episodes of excessive PM_{2.5} concentrations have occurred in many parts of the world. The World Health Organization (WHO) notes that about 90% of the worldwide population lives in areas where PM_{2.5} concentrations exceed safe limits (new.s.un.org/en/story/2022/04/1115492). As a major manufacturing power, China has long faced challenges from PM_{2.5} pollution. In classic regions such as the Yangtze River Delta and the Beijing-Tianjin-Hebei region, smoggy weather during autumn and winter once became a focal point of public concern. China issues the *Air Pollution Prevention and Control Action Plan* in 2013, marking the beginning of the systematic governance of PM_{2.5}. In 2020, the *14th Five-Year Plan* (from 2021 to 2025) explicitly set a binding target of a 10% reduction in PM_{2.5} concentrations in prefecture-level cities by 2025. This series of measures marks the entry of China's air pollution governance into a new phase of precision prevention and control, with a deep PM_{2.5} emission reduction as the core.

The achievement of PM_{2.5} pollution control goals is inseparable from the collaborative efforts of financial markets. Based on the Ministry of Ecology and Environment, to achieve the *14th Five-Year Plan* target of a 10% reduction in PM_{2.5} concentrations in prefecture-level cities, China's green investment demand in areas such as industrial emission reduction and clean energy substitution has exceeded 4 trillion yuan. Against this urgent funding demand, green finance has arisen as a critical engine to bridge the funding gap in air pollution governance and drive continuous compliance with PM_{2.5} standards. With the gradual improvement of China's green financial system, its supporting role in PM_{2.5} governance has become increasingly prominent. The *Guidelines on Establishing a Green Financial System* issued in 2016 explicitly proposed building a green financial system through instruments like green credit and green bonds to mobilize and motivate more social capital into green industries. This reflects the continuous expansion of China's green financial market and the accelerating innovation of green financial products. The government provides targeted support to key PM_{2.5} governance areas such as industrial emission reduction and clean energy substitution through instruments like green bonds and green credit, thereby providing strong momentum to break through

the funding bottleneck in PM2.5 pollution control and offering robust support to drive sustained declines in PM2.5 concentrations.

Despite a series of policies issued by relevant authorities, academic research on the following question remains scarce: Can green finance effectively reduce fine particulate matter (PM2.5) emissions? It is of substantial academic and practical significance to conduct research on this question against the backdrop of China's continuous systematic governance of PM2.5.

Compared with existing literature, this paper makes marginal contributions in the following aspects. First, this study focuses on the impact of green financial development on PM2.5 emissions. Existing literature predominantly revolves around influencing factors such as foreign investment (Cheng et al., 2020) [1], technological level (Sun et al., 2022; Liu, X., 2018) [2-3], urbanization level (Sun et al., 2023; Li et al., 2016) [4-5], and education level (Le et al., 2021) [6], but rarely explores the relationship between green finance and PM2.5 emissions. However, as a core tool of pollution and emission reduction policies, the actual effect of green finance on PM2.5 emission governance remains to be evaluated, and the regional characteristics of PM2.5 emissions further require references for targeted green financial policy formulation. Based on this, this paper uses a two-way fixed effects model to empirically analyze the influence of green financial development on PM2.5 emissions. Second, this study utilizes the panel data from 244 prefecture-level cities in China from 2016 to 2023. Due to data limitations, existing literature often relies on provincial-level data (Xiang et al., 2023; Zhou et al., 2023) [7-8]. Given that the heterogeneity of green financial effects can be accurately captured by city-level data, and considering that substantial disparities are exhibited in economic development, industrial structures, and environmental governance capabilities among Chinese prefecture-level cities, heterogeneous impacts across different regions and economic development levels are further investigated in this paper. Thus, empirical support is provided for the formulation of "city-specific policies" through such an investigation.

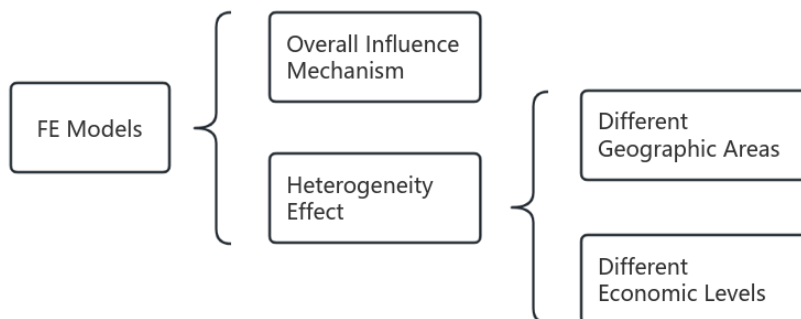


Figure 1. Research Framework.

2. Theoretical Foundation and Research Hypotheses

The theory of financial resource misallocation posits that policy guidance or market failures may lead to capital flowing into inefficient or high-pollution sectors (Stiglitz et al., 1981) [9]. Within the green finance framework, local governments pursuing short-term economic growth may tacitly allow green funds to flow into "pseudo-green" projects that nominally meet environmental standards but are actually high-emission (such as environmentally repackaged traditional industrial projects), rather than genuine clean energy or emission reduction technology innovation. This misallocation is one cause of green finance inefficiency (Li et al., 2023) [10], which exacerbates industrial PM2.5 emissions and offsets the environmental benefits of green finance.

The information asymmetry theory states that when one party in a market transaction holds superior information, it may lead to adverse selection and moral hazard (Akerlof, 1970) [11]. In the green finance sector, information asymmetry between issuers such as enterprises and regulators/investors can trigger greenwashing: enterprises may exaggerate the environmental benefits of projects to obtain green financing, while actually using funds for high-pollution activities (Schmittmann et al., 2022) [12]. Due to the lack of full-transparency information tracking

mechanisms, regulators struggle to effectively identify fund flows. This information imbalance weakens the environmental governance efficacy of green finance and may even lead to increased pollutant emissions. For example, based on the information asymmetry theory, if green bond issuance at the prefecture level lack strict information disclosure and third-party evaluation, funds may flow into non-green industries (Xu et al., 2022) [13], thereby leading to the promotion of PM2.5 emissions by green financial development.

Based on the above theories, this paper proposes the following hypothesis:

H1: The development of green finance will increase PM2.5 emissions.

3. Data and Model

3.1. Variables

3.1.1. Independent variable (Green Finance [GRB])

Grounded in the research of Shah et al. (2024) [14] and Cui et al. (2023) [15], this study focuses on green bonds at the prefecture-level city level, collects data on bond issuance and green bond issuance in each city, and constructs a green bond index as an indicator to measure green financial development. The choice of the green bond index as a measurement indicator stems from two key factors: First, green bonds serve as a core vehicle in the green financial system. Second, due to practical constraints in data collection at the prefecture-level city level, traditional green finance indicators often suffer from issues like data gaps, whereas green bond issuance data can be completely traced through public market platforms, providing a feasible foundation for index construction.

3.1.2. Dependent variable (Particulate Matter 2.5 per cubic meter [PM25])

Pollution reduction refers to reducing atmospheric pollutant emissions such as PM2.5 during the development process. Zeng et al. (2022) [16] used the PM2.5 concentration to measure environmental pollution governance. Based on this, this paper select the PM2.5 concentration of each prefecture-level city as the explanatory variable.

3.1.3. Control variables

Besides green finance, there are many other factors that influence PM2.5 emissions. Thus, this paper additionally controls the variables below. First, foreign direct investment (*FDI*) with affects PM2.5 concentrations. Second, government education expenditure intensity (*EDU*), Zhao et al. (2024) [17] and Ardoin et al. (2020) [18] note that government education expenditure intensity influences PM2.5 emissions. High government education expenditure intensity will raise the education level, individuals with higher education prefer to prefer environmentally friendly energy (Sarkodie et al., 2020) [19], thus reducing fine particulate matter emissions and lowering PM2.5 concentrations. Third, scientific and technological development level (*STE*), this study uses the ratio of "local fiscal expenditure on science and technology to local general public budget expenditure" as a proxy for scientific and technological development. Fourth, urbanization level (*URB*), which is evaluated by the percentage of urban population relative to total population in each city. Table 1 provides a brief description of each variable.

Table 1. Outline of variables.

	Variables	Description	Sources
Dependent Variable	<i>PM25</i>	Annual average concentration ($\mu\text{g}/\text{m}^3$)	NBS
Independent Variable	<i>GRB</i>	Total green bond issuance / Total bond issuance	Wind
	<i>FDI</i>	Actual foreign direct investment / GDP	Wind
	<i>URB</i>	Urban population / Total population	Wind
Control Variables	<i>STE</i>	Local fiscal expenditure on technology / Local general public budget expenditure	Wind
	<i>EDU</i>	Local fiscal expenditure on education / Local general public budget expenditure	Wind

3.2. Data processing

This paper utilizes panel data from 244 prefecture-level cities in China from 2016 to 2023, with other cities excluded due to severe data shortages. The annual mean concentration of PM2.5 and green finance data are obtained from official websites of authoritative institutions like the National Bureau of Statistics (NBS), as well as various statistical yearbooks, including specialized ones like the *China Urban Statistical Yearbook*.

Table 2. Statistical description of variables.

VARIABLES	N	SD	MEAN	MIN	MAX
<i>PM25</i>	1562	13.7362	37.8930	11.0000	116.0000
<i>GRB</i>	1187	0.1217	0.0299	0.0000	1.6667
<i>FDI</i>	1929	0.0049	0.0028	0.0000	0.0614
<i>URB</i>	1926	0.2338	0.4021	0.0346	1.0000
<i>STE</i>	1945	0.0221	0.0226	-0.0001	0.2091
<i>EDU</i>	1941	0.0389	0.1693	0.0146	0.3465

Table 2 shows the descriptive statistical analysis of each variable. By comparing the means and standard deviations of the variables, we find that the annual mean concentration of PM2.5 (*PM25*) holds a mean of 37.8930 and a standard deviation of 13.7362; green finance (*GRB*) retains a mean of 0.0299 and a standard deviation of 0.1217. This indicates that the annual mean concentration of PM2.5 (*PM25*) and the development level of green finance (*GRB*) among the 244 selected Chinese cities exhibit considerable variation.

3.3. Model

This paper develops the following fixed effects model to investigate the effect of green finance development on PM2.5 emissions:

$$PM25_{it} = \alpha_0 + \alpha_1 GRB_{it} + \alpha_k X_{it} + \mu_i + \theta_r + \epsilon_{ti} \quad (1)$$

Where, $PM25_{it}$ denotes the average concentration of PM2.5 in city i during period t ; α_0 is the intercept term; GRB_{it} denotes the level of green financial development in city i at time t ; X_{it} is the control variable vector, representing a series of control variables for city i in period t ; μ_i indicates the city fixed effects; θ_r indicates the time fixed effects; ϵ_{ti} represents the random error term.

4. Results and discussion

4.1. Baseline results

According to Eq. (1), this section employs a two-way fixed effects model (with both city and year fixed effects) to analyze the relationship between green finance (*GRB*) and PM2.5 concentration (*PM25*). Columns (1) to (5) of Table 3 report the fixed effects regression results with the stepwise inclusion of control variables. The results show that all coefficients of *GRB* are significantly positive at the 5% level, indicating a positive impact on the PM2.5 concentration in Chinese cities. In other words, green finance contributes to the increase in PM2.5 emissions, suggesting the existence of greenwashing. Xu et al. (2022) [20] pointed out that China's green bond market has significant greenwashing, and the market's concern about the authenticity of bonds' "greenness" is reflected through investors' pricing of greenwashing risks, which supports the conclusion drawn in this paper about greenwashing in China's green bonds based on PM2.5 emissions.

Table 3. Results of benchmark regression.

	(1)	(2)	(3)	(4)	(5)
	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>
<i>GRB</i>	3.066** (2.16)	3.068** (2.15)	3.046** (2.13)	3.009** (2.10)	2.952** (2.06)
<i>FDI</i>		37.594 (0.80)	43.235 (0.92)	42.490 (0.90)	41.010 (0.87)
<i>URB</i>			2.352 (0.49)	2.171 (0.45)	2.047 (0.42)
<i>STE</i>				-12.781 (-0.70)	-11.834 (-0.64)
<i>EDU</i>					9.152 (1.11)
_cons	32.824*** (12.01)	31.845*** (10.69)	29.492*** (5.35)	30.658*** (5.32)	29.798*** (5.04)
year	Yes	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes	Yes
N	1032	1027	1015	1015	1013
Within-R ²	0.6491	0.6472	0.6477	0.6480	0.6491

Notes: Figures in parentheses are t-values, with ***, **, and * denoting statistical significance at the 1%, 5%, and 10% levels in turn.

4.2. Robustness test

Though the fixed-effects panel model used in the basic regression can address part of the endogeneity, the endogeneity issues in it are yet fully resolved. There are two reasons. Firstly, several variables affecting annual average PM2.5 concentration has controlled by this paper, but potential unobservable characteristics remain. Once statistical correlation emerges between key variables and omitted variables in the error term, empirical results will inevitably suffer from bias. Secondly, there may be bidirectional causality between green finance and PM2.5 concentration. From one perspective, the evolution of green finance can aid green economic transformation, and in the meantime contribute to the decrease in PM2.5 concentration; on the other hand, cities with high PM2.5 concentrations may face greater pollution reduction demands and higher green financing needs, thereby compelling local governments to foster green finance. Thus, this paper deploys the following robustness tests to address endogeneity: (1) shortening the sample period (2016–2022); (2) adding two additional control variables.

4.2.1. Shortening the sample period (2016–2022) (A)

We re-estimated the basic model using data from 2016 to 2022 to avoid the interference of multiple green financial policy adjustments in 2023 on research conclusions. The green financial policies introduced in China in 2023 significantly strengthened the regulatory framework and market rules, which may have caused structural changes in the causal relationship between green finance and PM2.5 emissions. As displayed in Columns (1) to (5) of Table 3, the coefficient of green finance (*GRB*) was positive at the 1% significance level, proving that the basic regression results are valid.

4.2.2. Adding two additional control variables (B)

To reduce the possibility of omitted control variables, we added two additional control variables: industrial structure upgrading (*IND*) and government intervention (*GOV*). The industrial structure upgrading index is used as a proxy for industrial structure. According to Clark's theorem (Clark, 1967) [21-22], the industrial structure is calculated as " $IND = \text{primary industry share} + 2 * \text{secondary industry share} + 3 * \text{tertiary industry share}$ ". Government intervention (*GOV*) is measured by the ratio of "local general public budget expenditure to local annual GDP", and the IMF (2016;2023) [23-24] has confirmed the promoting effect of government expenditure on pollution

reduction. As shown in Column (6) of Table 4, the coefficient of green finance (*GRB*) is positive at the 5% significance level, confirming the validity of the basic regression results.

Table 4. Results of robustness test.

	A				B	
	(1)	(2)	(3)	(4)	(5)	(6)
	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>	<i>PM25</i>
<i>GRB</i>	4.523*** (2.69)	4.532*** (2.65)	4.515*** (2.64)	4.526*** (2.64)	4.443*** (2.59)	2.963** (2.07)
<i>IND</i>						0.018 (0.33)
<i>GOV</i>						-2.579 (-0.49)
<i>FDI</i>		28.713 (0.44)	46.280 (0.70)	46.126 (0.69)	44.768 (0.67)	40.632 (0.86)
<i>URB</i>			6.536 (1.16)	6.580 (1.16)	6.129 (1.08)	2.324 (0.48)
<i>STE</i>				3.429 (0.16)	3.909 (0.18)	-11.803 (-0.64)
<i>EDU</i>					5.992 (0.63)	7.836 (0.90)
_cons	33.158*** (9.70)	32.947*** (9.54)	26.555*** (4.11)	26.261*** (3.90)	26.062*** (3.79)	30.153*** (5.04)
year	Yes	Yes	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes	Yes	Yes
N	839	834	823	823	821	1013
Within-R ²	0.6697	0.6679	0.6693	0.6693	0.6705	0.6492

Notes: Figures in parentheses are t-values, with ***, **, and * denoting statistical significance at the 1%, 5%, and 10% levels in turn.

4.3. Heterogeneity effect

4.3.1. Economic development level's heterogeneous influence

The benchmark regression results show that green finance increases PM2.5 emissions. Next, this paper investigates whether this impact varies across different economic levels. Specifically, this section uses a GDP of 1 trillion yuan in 2023 as the grouping criterion: cities with a GDP above 1 trillion yuan are classified into the developed group, and those below into the underdeveloped group (www.newschinamag.com/newschina/articleDetail.do?article_id=5674§ion_id=15&magazine_id=45). We then conduct a grouped regression analysis with stepwise inclusion of control variables.

Columns (1) to (10) in Table 5 display the grouped regression results. In Columns (1) to (5) for the Developed Group, the coefficient of green finance (GF) is negative, but no statistically significant results were observed. In Columns (1) to (5) for the Underdeveloped Group, the GF coefficient is significantly positive at the 5% level, proving that green finance fails to suppress PM2.5 emissions in regions with poorer economic development and instead leads to an increase in emissions. Liu et al. (2025) [25] argues that regulatory intervention can effectively reduce the probability of greenwashing by enterprises, thereby mitigating systemic greenwashing risks in China’s green bond market. Regions with better economic development (such as southeastern coastal areas) have sound and complete regulatory systems (Chen et al., 2019) [26], which explains why green finance shows an inhibiting effect on PM2.5 emissions in these regions. The insignificance of this effect may be due to the early and effective implementation of environmental pollution control in developed areas, making the pollution reduction effect of green finance less obvious. Conversely, greenwashing is more likely to occur in less developed regions due to imperfect regulations and insufficient supervision.

Table 5. Heterogeneity effect results.

		Economic development level									
PM25	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
	Developed group					Underdeveloped group					
<i>GRB</i>	0.044 (0.01)	-0.685 (-0.16)	-0.871 (-0.20)	-0.419 (-0.10)	-0.728 (-0.17)	3.284* (2.14)	3.305* (2.14)	3.291* (2.13)	3.278* (2.11)	3.275* (2.11)	
<i>FDI</i>		134.58 7 (1.44)	135.46 9 (1.42)	120.99 8 (1.25)	125.76 2 (1.19)		22.914 (0.43)	29.495 (0.55)	29.517 (0.55)	29.351 (0.54)	
<i>URB</i>			1.203 (0.15)	1.564 (0.20)	-0.024 (-0.00)			2.419 (0.41)	2.341 (0.39)	2.935 (0.49)	
<i>STE</i>				- 30.566 (-1.01)	- 27.192 (-0.88)				-2.535 (-0.11)	-0.569 (-0.02)	
<i>EDU</i>					3.606 (0.15)					8.746 (0.95)	
_cons	47.652 *** (21.92)	47.099 *** (21.43)	39.015 *** (16.92)	39.518 *** (16.75)	44.258 *** (4.93)	33.021 *** (11.44)	32.424 *** (10.17)	29.956 *** (4.55)	30.233 *** (4.28)	28.509 *** (3.90)	
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
city	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
N	171	169	167	167	166	861	858	848	848	847	
Within -R ²	0.8172	0.8207	0.8217	0.8230	0.8253	0.5985	0.5953	0.5955	0.5955	0.5962	

Notes: Figures in parentheses are t-values, with ***, **, and * denoting statistical significance at the 1%, 5%, and 10% levels in turn.

4.3.2. Geographical location level's heterogeneous influence

Various geographical regions differ in resource endowments and policies, which may lead to heterogeneity in the influence of green finance on environmental pollution. In 2011, the National Bureau of Statistics of China divided the country into four regions: East, Central, West, and Northeast. Due to the small sample size of the Northeast, this paper merges the Northeast with the East (After China’s reform and opening-up, the economic growth rate of the Northeast has slowed, and its industrial structure has gradually converged with that of eastern coastal areas (such as Jiangsu, Zhejiang, Shanghai, and Guangdong). It has even been incorporated into the eastern development framework in policy orientation, hence the merger).

Columns (1) to (15) in Table 6 present the grouped regression results. In Columns (1) to (5) for the Eastern Group, the coefficient of green finance (GF) is negative, indicating that green finance in the East can inhibit PM2.5 emissions, though the result is not significant. In Columns (6) to (10) for the Central Group, the GF coefficient is significantly positive at the 5% level, proving that green finance in the Central region fails to suppress PM2.5 emissions and instead promotes them. In Columns (11) to (15) for the Western Group, the GF coefficient is negative, suggesting that green finance development in the West may lead to PM2.5 emissions, but the result is not significant.

In the central and western areas, the number of heavy-pollution enterprises has surged due to resource development and industrial transfer, and polluting firms are more likely to engage in greenwashing (Shi et al., 2023) [27]. The insignificant pollution reduction effect of green finance in the East may be attributed to the rapid proliferation of green financial instruments (in both types and quantity) in the current era, which has diluted the role of green bonds.

Table 6. Heterogeneity effect results.

Geographic location		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
PM25		Eastern group			Central group				Western group							
GRB		-1.155 (-0.60)	-1.226 (-0.63)	-1.391 (-0.72)	-1.321 (-0.68)	-1.361 (-0.71)	6.825*** (2.70)	6.846*** (2.70)	6.826*** (2.70)	6.381** (2.53)	6.298** (2.50)	2.055 (0.58)	2.269 (0.64)	2.238 (0.63)	2.211 (0.62)	2.182 (0.61)
FDI			43.580 (0.95)	55.086 (1.18)	54.917 (1.18)	42.811 (0.93)		32.211 (0.17)	-4.409 (-0.02)	21.383 (0.11)	24.350 (0.13)		-474.190* (-1.88)	-434.015* (-1.71)	-449.188* (-1.74)	-449.543* (-1.74)
URB				9.590 (1.27)	9.656 (1.28)	8.634 (1.15)			-13.430 (-1.51)	-15.676* (-1.76)	-15.862* (-1.78)			6.740 (0.77)	6.577 (0.75)	6.944 (0.78)
STE					38.178 (1.35)	47.240* (1.68)				-66.626** (-2.16)	-67.712** (-2.19)				-15.036 (-0.35)	-13.381 (-0.31)
EDU						40.118*** (2.88)					21.822 (1.09)					2.915 (0.26)
_cons		33.723 *** (13.33)	32.673 *** (11.83)	23.283 *** (2.97)	20.226 ** (2.48)	16.805 ** (2.03)	72.817 *** (17.88)	62.956 *** (15.39)	72.779 *** (17.29)	72.067 *** (17.19)	70.291 *** (7.47)	44.119 *** (7.76)	42.875 *** (9.70)	33.810 *** (3.69)	34.288 *** (3.70)	33.310* ** (3.32)
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
city	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	427	425	416	416	415	346	345	345	345	344	259	257	254	254	254	
Within-R ²		0.7298	0.7294	0.7339	0.7355	0.7426	0.6046	0.6014	0.6048	0.6118	0.6137	0.6384	0.6400	0.6363	0.6366	0.6367

Notes: Figures in parentheses are t-values, with ***, **, and * denoting statistical significance at the 1%, 5%, and 10% levels in turn.

5. Conclusions and policy implications

5.1. Main findings

Industrialization and urbanization are accelerating. This has worsened air pollution. PM2.5 emissions pose growing environmental risks, threatening human health and ecological balance. In response, countries are stepping up air pollution control. They actively promote green transitions focused on reducing PM2.5. This drives the development of green finance in environmental governance. This paper utilizes China’s city-level panel data from 2016 to 2023. It examines how green financial development affects PM2.5 emissions. Benchmark regression results show a surprising trend: green finance increases PM2.5 emissions. Robustness tests were conducted, including shorter sample periods and added control variables. The emission-promoting effect remained significant. Heterogeneity analysis reveals regional differences. In underdeveloped regions, green finance significantly induces PM2.5 emissions. But in developed regions, its inhibitory effect is not significant. In eastern and western regions, green finance has no notable impact. However, in central regions, it significantly increases emissions. This suggests a problem: some green bonds may involve greenwashing. They claim to support environmental projects, but actual fund use fails to improve air quality. It may even indirectly worsen PM2.5 pollution. Such misallocation of capital weakens green finance’s role in controlling air pollution. It also challenges China’s goals for improving air quality.

5.2. Policy recommendations

Based on the research outcomes, this paper specifically proposes four policy recommendations to enhance how green finance promotes China’s PM2.5 emission reduction:

First, regulatory authorities should improve the green bond supervision and certification system by establishing stricter issuance review mechanisms, clarifying definition standards for air pollution control projects, refining fund use scopes, and intensifying penalties for greenwashing.

Second, regulators must strengthen information disclosure and transparency requirements, mandating enterprises and financial institutions issuing green bonds to regularly disclose standardized data on PM2.5 reduction effects of funded projects .

Third, the government should optimize incentive and constraint mechanisms by providing tax incentives, fiscal subsidies, and other preferential policies to green bond projects that genuinely contribute to PM_{2.5} reduction, depriving policy support and restricting subsequent issuances for greenwashing-involved bonds.

Fourth, Governments and regulators should implement differentiated green finance policies by region: tighten green bond admission standards in central and less-developed regions, focusing on supporting direct emission reduction projects like clean energy substitution; strengthen innovation supervision in developed regions, promote cross-regional fund allocation through inter-regional coordination mechanisms.

Reference

- [1] Cheng, Z., Li, L., & Liu, J. (2020). The impact of foreign direct investment on urban PM_{2.5} pollution in China. *Journal of Environmental Management*, 265, 110532.
- [2] Sun, X., Wang, Z., & Loh, L. (2022). Exploring the effect of digital economy on PM_{2.5} pollution: The role of technological innovation in China. *Frontiers in Environmental Science*, 10, 904254.
- [3] Liu, X. (2018). Effect of energy development and technological innovation on PM_{2.5} in China: A spatial Durbin econometric analysis. *Discrete Dynamics in Nature and Society*, 2018, 2148318.
- [4] Sun, J., Zhou, T., & Wang, D. (2023). Effects of urbanisation on PM_{2.5} concentrations: A systematic review and meta - analysis. *Science of The Total Environment*, 900, 166493.
- [5] Li, G., Fang, C., Wang, S., & Sun, S. (2016). The effect of economic growth, urbanization, and industrialization on fine particulate matter (PM_{2.5}) concentrations in China. *Environmental Science & Technology*, 50(21), 11452–11459.
- [6] Le, T. H., Chang, Y., & Park, D. (2021). Governance, environmental vulnerability, and PM_{2.5} concentrations: International evidence. *Journal of Environmental Management*, 298, 113548.
- [7] Xiang, W., Qi, Q., & Gan, L. (2023). Non-linear effects of green finance on air quality in China: New evidence from a panel threshold model. *Frontiers in Ecology and Evolution*, 11, 1162137.
- [8] Zhou, W., & Wu, X. (2023). Does green finance reduce environmental pollution?—A study based on China's provincial panel data. *Environmental Science and Pollution Research*, 30(44), 83657–83677.
- [9] Stiglitz, J. E., & Weiss, A. (1981). Credit rationing in markets with imperfect information. *American Economic Review*, 71(3), pp. 393–410.
- [10] Li, X., Wang, X., Wang, K. H., & Su, C. W. (2023). Green credit and PM_{2.5}: A time-varying perspective in China. *Ekonomiska Istrazivanja*, 36(2).
- [11] Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics*, 84(3), 488–500.
- [12] Schmittmann, J. M., & Gao, Y. (2022). Green bond pricing and greenwashing under asymmetric information. *IMF Working Papers* (No. 246).
- [13] Xu, G., Lu, N., & Tong, Y. (2022). Greenwashing and credit spread: Evidence from the Chinese green bond market. *Finance Research Letters*, 48, 102927.
- [14] Shah, S. S., Murodova, G., & Khan, A. (2024). Achieving zero emission targets: The influence of green bonds on clean energy investment and environmental quality. **Journal of Environmental Management**, 364.
- [15] Cui, Y., Zhong, C., Cao, J., & Guo, M. (2023). Can green finance effectively mitigate PM_{2.5} pollution? What role will green technological innovation play? *Journal of Environmental Planning and Management*, 10.1177/0958305X231204030.
- [16] Zeng, Y., Wang, F., & Wu, J. (2022). The impact of green finance on urban haze pollution in China: A technological innovation perspective. *Energies*, 15(3), 801.
- [17] Zhao, N., Wang, C., Shi, C., & Liu, X. (2024). The effect of education expenditure on air pollution: Evidence from China. *Journal of Environmental Management*, 359, 121006.
- [18] Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, 241, 108224.

- [19] Sarkodie, S.A., Adams, S., Owusu, P.A., Leirvik, T., Ozturk, I., 2020. Mitigating degradation and emissions in China: the role of environmental sustainability, human capital and renewable energy. *Sci. Total Environ.* 719, 137530.
- [20] Xu, G., Lu, N., & Tong, Y. (2022). Greenwashing and credit spread: Evidence from the Chinese green bond market. *Finance Research Letters*, 48, 102927.
- [21] Clark, C. G. (1967). *Population growth and land use*. St. Martin's Press.
- [22] Clark, C. G. (1967). *The economics of irrigation*. Pergamon Press.
- [23] International Monetary Fund. (2016). Fiscal policy for a sustainable environment. In *Fiscal Dimensions of Sustainable Development* (pp. 33–58). IMF Publishing.
- [24] International Monetary Fund. (2023). Environmental taxes and government expenditures on environmental protection. In *Data for a Greener World: A Guide for Practitioners and Policymakers* (Chapter 3). International Monetary Fund.
- [25] Liu, H.-Z., Kou, Z.-X., Sun, Y.-T., & Zhu, P.-H. (2025). Governing greenwashing by government regulation: evidence from China's listed companies. *Applied Economics Letters*, DOI: 10.1080/13504851.2025.2489101.
- [26] Chen, S., & Li, W. (2019). Local government debt and regional economic growth in China. *China Political Economy*, 2(2), 330–353. DOI: 10.1108/CPE - 10 - 2019 - 0028
- [27] Shi, X., Ma, J. T., & Yue, L. (2023). Green bonds: Green investments or greenwashing? *International Review of Financial Analysis*, 87, 102850.