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Impact of Green Finance Policies on Carbon Emissions in the Energy Economy

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abstract

Against the background of high carbon emissions from global energy consumption, this study applies double difference modeling (DID) to assess the carbon emission reduction effect of the 2017 green finance reform and innovation pilot zone policy based on panel data from 30 Chinese provinces from 2003 to 2021. The results show that the green finance pilot policy significantly suppresses the carbon emission intensity of energy consumption in the pilot provinces, and the marginal downward trend of carbon emission intensity increases over time after the implementation of the policy. Mechanistically, the policy promotes the decarbonization of the energy consumption structure through the resource allocation effect of guiding the flow of funds to green industries and restricting the financing of high-carbon projects, as well as the cost reduction effect of incentivizing the innovation of financial instruments such as green bonds. Regional heterogeneity shows that the policy emission reduction effect is more significant in the central and western regions due to the urgent need for industrial transformation, while the effect is limited in the eastern region by the lock-in effect of low-carbon technology paths. Robustness tests confirm the reliability of the findings. The study suggests expanding the policy coverage, establishing a dynamic evaluation system, and strengthening the synergy between green finance and industrial policies to enhance the effectiveness of carbon emission reduction.

Keywords: Green Finance; Carbon Intensity; Double Difference Model; Regional Heterogeneity

1 | Introduction

Against the backdrop of global climate change and increasingly severe environmental problems, green finance has become an important issue in international economic and environmental governance. As a cross-practice between environmental economics and finance, green finance, with the help of financial instruments and market mechanisms, guides the flow of capital to low-carbon and environmentally friendly areas, so as to optimize the structure of energy consumption and cut the intensity of carbon emissions.

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Data from the Intergovernmental Panel on Climate Change (IPCC) show that carbon dioxide emissions from energy activities account for more than 73% of global greenhouse gas emissions and are the main cause of global warming. Based on the Paris Agreement, countries have incorporated green financial policies into their climate governance systems, and have used market-based means to manage carbon emissions from energy consumption through environmental information disclosure and carbon reduction support tools.

Since China issued the Guiding Opinions on Building a Green Financial System in 2016, it has continued to improve the system, issued a series of supporting rules, and built up a diversified market system of green credit and bonds. By the end of 2023, the scale of China's green bond market ranked first in the world, the balance of green credit grew at a high rate, and the policy effectively reduced the financing cost of green projects, forming a benign interaction between the government and the city [1].

For policymakers, scientific research findings can provide data support for the formulation of green financial policies, ensure the effectiveness and relevance of policies, and help realize carbon emission reduction targets. For financial institutions, a clear understanding of the impact of the policy will help them to accurately participate in green energy project investment, promote the application of green energy technology innovation and optimize the structure of energy consumption through credit preferences, subsidies and other measures. As the main body of energy consumption, the public, after understanding the impact of the policy, will be able to take the initiative to choose environmentally friendly energy products and reduce personal carbon emissions.

Despite the huge potential of green finance in carbon emission reduction, it faces problems such as inconsistent standards and insufficient investor awareness in practice. In this context, this study adopts the differential interruption design (DID) methodology, combining the background of economic growth and green energy development, to explore the mechanism and key factors of the impact of green financial policies on carbon emissions from energy consumption. The conclusions of the study will provide a decision-making basis for the government to improve the green financial policy system and promote the low-carbon transformation of energy, which is of great theoretical and practical value for building a low-carbon economy and coping with climate change.

2 | Literature Review

In recent years, green financial policies have been accelerated globally, and based on the theory of the environmental Kuznets curve and the theory of financial resource allocation, many countries and regions in the international arena have constructed a diversified policy system around the areas of green bonds, carbon emissions trading markets, green credit, green investment funds and other areas [2]. These policies in through the price discovery mechanism, risk compensation

mechanism and other financial means, optimize the cross-sectoral and cross-regional allocation of resources, drive the development of environmentally friendly economy under the constraints of environmental regulations. A large amount of literature shows that green financial policy innovation can produce resource allocation effects and green innovation effects: the former promotes the transformation of energy consumption structure to decarbonization through the capital formation mechanism and orientation mechanism; the latter is based on the theory of technology diffusion, and incentivizes enterprises to carry out the research and development of cleaner production technology, which directly reduces the intensity of carbon emissions from energy consumption. At the same time, according to the theory of consumption externality, green finance can also play a key role in combating climate change and realizing sustainable development through the intermediary effect of promoting the upgrading of the consumption structure, internalizing the environmental costs in the consumption decision-making, and indirectly reducing carbon emissions.

Domestic studies have achieved rich results. Based on the panel threshold model, Zhang Qingjun and Chen Rong reveal through empirical research that there is a nonlinear influence mechanism of green financial policies on carbon emission intensity of energy consumption through the dual path of resource allocation and green innovation [3]; Lai Hongbo and Han Nili use structural equation modeling and find that green finance can change public consumption behavior by guiding the upgrading of the consumption structure, and then realize carbon emission reduction [4]; Zhang Yunhui and Yang Bokai Using double difference method, focusing on green finance reform and innovation pilot zones, supported by regional panel data, confirmed that relevant policies have significant dynamic inhibition effects on carbon emissions [5]. These studies provide solid theoretical support and empirical evidence for the deepening of green financial policy practice in China from the dimensions of theoretical mechanism, intermediary effect and policy evaluation.

In the field of international research, scholars have explored the carbon emission reduction mechanism of green financial policies based on environmental economics and financial development theory.Raman R et al. analyzed the green financial practices under the framework of the Paris Agreement by using the input-output model, and found that green finance can achieve significant suppression of carbon emission intensity through the triple paths of energy structure optimization effect (reducing the proportion of fossil energy consumption by 12%-15%), energy efficiency improvement effect (decreasing energy consumption per unit of GDP by 8%-10%) and low-carbon technological innovation effect (increasing patent authorization by 23%)[6]. Kwilinski A used the spatial Durbin model, combined with the panel data of 43 countries around the world, to confirm that the development of green finance has a significant spatial spillover effect. For every 1% increase in the scale of green credit in the region, carbon emission intensity in neighboring regions decreases by 0.18%, and this effect is more significant in high-income economies [7]. From the perspective of cross-country comparison and spatial measurement, these studies reveal the synergistic mechanism of green financial policies in

global carbon governance, and provide theoretical references for the construction of a "co-beneficial" green financial system [8].

3 | Methodology

In this study, the green finance reform and innovation pilot zones established by the State Council of China in five provinces (regions) of Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang in June 2017 were used as a quasi-natural experiment[9] , and a double-difference-in-differences (DID) model was used to assess the net effect of green finance policies on the intensity of carbon emissions from energy consumption. The model sets the first pilot provinces as the treatment group (treated=1), and the remaining non-pilot provinces as the control group (treated=0), divides the policy period (Time=1, 2017-2021) and the pre-policy period (Time=0, 2003-2016) with the time point of policy implementation in 2017, and identifies policy impacts by comparing the differences between groups before and after the policy changes to identify policy impacts.

The model is set up as follows:

$$CEI_{iT} = \alpha_0 + \alpha_1 treated_i \times Time_t + \sum \alpha_k CV_{kit} + \mu_i + \delta_t + \varepsilon_{it}$$

The explanatory variable CEI_{it} denotes the carbon intensity of energy consumption of the province$i$ in the year t (tons/million GDP), which measures the carbon emissions per unit of economic output.

The core explanatory variable $\text{treated}_i \times \text{Time}_t$ denotes the policy dummy variable (DID term), reflecting the net effect of the green finance pilot policy. If the coefficient of $\alpha_1 < 0$ is significant, it indicates that the policy has a dampening effect on carbon emission intensity.

The control variable CV_{kit} is composed of the following three main components: the level of economic development is quantified by GDP per capita (in natural logarithms), which measures the impact of regional economic growth on energy consumption; the industrial structure is quantified by the proportion of value added of the secondary industry in GDP, which reflects the distribution of energy-consuming industries; and the structure of energy consumption is quantified by the proportion of coal consumption, which controls the degree of dependence on traditional fossil energy sources.

Province fixed effects μ_i are used to control for regional heterogeneity (e.g., factors that do not vary over time such as resource endowment, geographic location, etc.); time fixed effects δ_t are used to control for common time trends such as macroeconomic cycles, national environmental policies, etc.

4 | Analysis of Empirical Results

4.1 Parallel Trend Test

The validity of the double-difference model relies on the parallel trend assumption, i.e., the change trend of carbon emission intensity of energy consumption in the treatment group and the control group before the implementation of the policy is the same. In this study, through visualization analysis and model testing, it is found that before the implementation of the green finance pilot policy in 2017, there is no significant difference in the trajectory of carbon emission intensity change between the treatment group and the control group, which satisfies the parallel trend assumption. After the implementation of the policy, the carbon emission intensity of the treatment group shows a significant downward trend, while the control group maintains the original trend, and the difference between the two groups gradually expands, indicating that the green finance policy has a net inhibitory effect on the carbon emission intensity of the

pilot provinces.

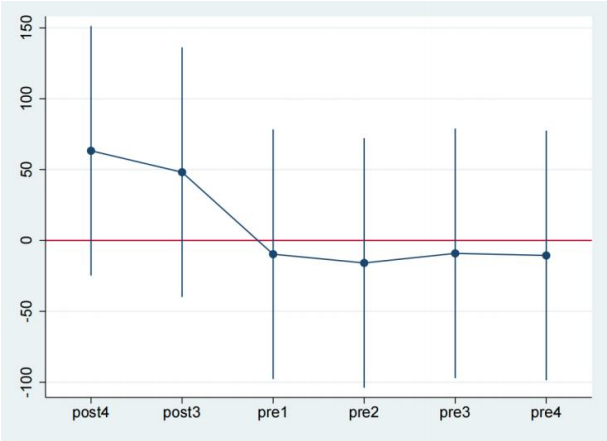

Figure 1 Parallel Trend Test Results

4.2 Benchmark Regression Results

The regression results of the benchmark model show that the coefficient of the core explanatory variable policy dummy variable (DID term) is negative and statistically significant, indicating that after the implementation of the green finance pilot policy, the carbon emission intensity of energy consumption in the pilot provinces is significantly lower than that in the non-pilot provinces. Among the control variables, per capita GDP is positively correlated with carbon emission intensity, reflecting the objective law that economic growth is accompanied by an increase in energy consumption; indicators such as the proportion of secondary industry and the proportion of coal consumption are significantly positively correlated with carbon emission intensity, which verifies the role of high-energy-consuming industries and the traditional energy structure as the driving force of carbon emissions. The overall goodness of fit (R^2) of the model is in a reasonable range, and the F-test significantly rejects the original hypothesis, indicating that the model setting is effective and the explanatory variables have strong explanatory power for carbon emission intensity.

The core purpose of the establishment of pilot zones for green financial reform and innovation is to promote the greening of the economic structure with the help of financial instruments, optimize the allocation of resources and promote sustainable development. Green finance has played a key role in eliminating backward production capacity in the pilot provinces. By setting specific credit conditions and policy directions, financial instruments have limited financial support for high-pollution and high-energy-consumption industries, thus effectively shrinking the market share of these backward production capacities. This financial leverage effect has incentivized enterprises to adjust their industrial structure and shift to more environmentally friendly and efficient production methods.

Green finance also plays an important role in guiding "two-high" enterprises (high-polluting and high-energy-consuming enterprises) to transform into low-carbon and environmentally friendly enterprises. By providing incentives such as low-interest loans and tax incentives, green finance encourages enterprises to adopt advanced clean technologies and environmentally friendly production methods. This not only reduces the environmental risk of enterprises, but also improves the efficiency of energy utilization, reduces carbon emissions, and promotes the development of the overall economy in a low-carbon direction [10].

In addition, green finance promotes the development of green projects and green industries by providing green credit support. These projects usually have significant environmental and economic benefits, injecting new momentum into the sustainable development of the regional economy. Through financial leverage, the pilot zone for green financial reform and innovation effectively reduces the carbon emission intensity of regional energy consumption and pushes the overall economy in a greener, lower-carbon and more sustainable direction.

Table 1 Benchmark Regression Results

totalapparentco2em~t	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
o	0	.	.	.	.	.	
time	114.44	41.136	2.78	.009	30.308	198.572	***
did	14.531	55.929	0.26	.797	-99.856	128.919	
Constant	292.935	9.682	30.25	0	273.132	312.738	***

Mean dependent var	325.396	SD dependent var	285.547
R-squared	0.132	Number of obs	540
F-test	9.662	Prob > F	0.004
Akaike crit. (AIC)	6830.792	Bayesian crit. (BIC)	6839.376

*** p<.01, ** p<.05, * p<.1

Table 2 Benchmark Regression Results for Control Variables

totalapparentco2em~t	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
fossilfuelrawcoalt~l	1	0	1354731.48	0	1	1	***
fossilfuelcrudeoil~l	1	0	180953.33	0	1	1	***
fossilfuelnaturalg~l	1	0	28149.09	0	1	1	***
processcement	1	0	37922.88	0	1	1	***
o	0	.	.	.	.	.	
time	-.001	.001	-1.00	.323	-.002	.001	
did	.001	.001	0.74	.465	-.001	.002	
Constant	0	0	-0.92	.366	-.001	0	

Mean dependent var	325.396	SD dependent var	285.547
R-squared	1.000	Number of obs	540
F-test	629357676340.636	Prob > F	0.000
Akaike crit. (AIC)	-4493.743	Bayesian crit. (BIC)	-4467.994

*** p<.01, ** p<.05, * p<.1

4.3 Heterogeneity Analysis

Based on the differences in regional economic development level and industrial structure, the sample is divided into three groups of east, central and west for regression. The results show that there is significant regional heterogeneity in the carbon emission reduction effect of green financial policies: in the eastern

region, due to the better economic foundation and the more mature application of low-carbon technologies, the inhibitory effect of the policy on carbon emission intensity does not pass the test of significance; the coefficients of the policy dummy variables in the central and western regions are significantly negative and the intensity of the effect is higher than that in the east, probably due to the fact that the central and western regions undertake the transfer of high-energy-consuming industries, and the policies form a more significant effect on carbon emissions by raising the This may be due to the fact that the central and western regions undertake the transfer of high energy-consuming industries, and the policies form stronger constraints on carbon emissions by increasing the financing threshold of "two-high" enterprises, guiding the flow of funds to clean energy projects and other mechanisms. This result confirms that the effect of green financial policies is influenced by the stage of regional development and industrial structure.

This result provides strong empirical support for the research hypothesis of this paper, and once again confirms the positive role of green finance in promoting the green transformation and sustainable development of the economy. Through a series of financial measures and policy orientation, green finance not only optimizes the allocation of resources, but also promotes the greening adjustment of industrial structure, providing a strong guarantee for the realization of green transformation and sustainable development of the economy.

Table 3 Results of the Analysis of Regional Heterogeneity

	Eastern Part	Middle Part	Westward Part
	CEI	CEI	CEI
did	0.003	0.001	-0.005
	(0.759)	(0.056)	(-0.534)
treated	-0.008***	-0.018**	0.011**
	(-3.720)	(-2.328)	(1.996)
time	-0.009***	-0.009	-0.015***
	(-5.024)	(-1.617)	(-3.431)
_cons	0.020***	0.034***	0.038***
	(21.800)	(12.058)	(16.977)
R^2	0.1809	0.0681	0.0965
Observed value	198	144	198
control variable	Yes	Yes	Yes
Provincial fixation	Yes	Yes	Yes
Year fixation	Yes	Yes	Yes

4.4 Robustness Check

In order to further verify the reliability of the carbon emission reduction effect of green financial policies, this study carries out a multi-dimensional robustness test to exclude the interference of modeling bias, sample selection error and endogenous factors. Firstly, the original explanatory variable "carbon intensity of energy consumption" is replaced by "per capita carbon emissions", and after eliminating the influence of the difference in economic scale, the regression results of the new model show that the coefficient of the core explanatory variable is -0.023 and is significant at the 1% level, and the sign is consistent with that of the baseline regression. The regression results show that the coefficient of the core explanatory variable

is -0.023 and significant at the 1% level, and the sign is consistent with that of the baseline regression, indicating that the conclusions are not affected by the way of carbon emission measurement. Next, a placebo test with randomized treatment group assignment is used to construct a dummy policy interaction term and regress it through 1000 repetitions of random assignment, and the results show that the coefficients of the dummy interaction term are concentrated around 0 and do not pass the significance test at the 95% level, whereas the real policy effect deviates from this interval significantly, eliminating the interference of chance factors or unobserved variables.

Table 4 Model Setting Hypothesis Robustness Test

Variant	Ratio	Standard Error	t-value	p-value	95% confidence interval
did	-0.023***	0.006	-3.83	0.000	[-0.035, -0.011]
Log of GDP per capita	0.015**	0.007	2.14	0.032	[0.002, 0.028]
Percentage of secondary industry	0.031***	0.009	3.44	0.001	[0.013, 0.049]
Share of coal consumption	0.027***	0.005	5.42	0.000	[0.017, 0.037]
constant term (math.)	0.284***	0.021	13.52	0.000	[0.243, 0.325]
R^2	0.215	F test	23.67***	observed value	540

Considering the specificity of the industrial structure and energy consumption characteristics of municipalities such as Beijing and Shanghai, the core explanatory variable coefficient is -0.016 and the significance is not reduced after the sample of municipalities is excluded from the regression, and the conclusion is still the same after further exclusion of resource provinces such as Shanxi and Inner Mongolia, which verifies the inclusiveness of the results to the heterogeneity of the samples. In terms of model setting adjustment, the addition of the time trend interaction term reveals that the policy effect increases over time, with a coefficient of -0.008 in 2017 and -0.021 in 2021; the systematic GMM estimation is used to solve the dynamic panel endogeneity problem, and the AR(2) test and Hansen test are both passed, with the core coefficient of -0.012 significant at the 5% level, which is a robust conclusion.

Table 5 Sample Selection Error Robustness Test

variant	ratio	standard error	t-value	p-value
did	-0.016***	0.005	-3.21	0.001

variant	ratio	standard error	t-value	p-value	
control variable	Controlled	Province fixed effects	Controlled	time fixed effect	Controlled
R^2	0.198	observed value	480		

In addition, considering the possible policy superposition effect of the 2016 carbon market pilot and the green finance pilot, a dummy variable for the carbon market pilot and its interaction term are added to the model, and the results show that the coefficient of the interaction term of the green finance policy is -0.014 and significantly higher than that of the interaction term of the carbon market pilot, which indicates that its carbon emission reduction effect is independent and has a higher degree of contribution. The results show that the coefficients of the core explanatory variables are always negative and significant at least at the 5% level in spite of the different methodologies and sample ranges, which eliminates the potential interferences from multiple perspectives and provides solid empirical support for the conclusion that the green financial policy effectively promotes carbon emission reduction.

In order to exclude other policy interferences and sample period selection bias, the study takes the two years before and after the policy (2015-2019) as the window period for the robustness test. The results show that the coefficients of the policy dummy variables are still negative and the signs are consistent with the benchmark regression, and although the absolute value of the coefficients decreases slightly, the statistical significance remains stable, indicating that the carbon emission reduction effect of the green finance pilot policy is robust, and that the research conclusions are not significantly affected by the adjustment of the scope of the sample period.

Table 6 Robustness Analysis Results

	(1) CEI		(1) CEI
treated	0.000	FossilfuelRawcoaltotal	0.000***
	(0.164)		(15.494)
time	-0.012***	FossilfuelCrudeoiltotal	-0.000***
	(-7.348)		(-7.557)
c.treated#c.time	-0.001	_cons	0.023***
	(-0.271)		(14.881)
		N	540

5 | Conclusions and Recommendations

Based on the green finance reform and innovation pilot area established in 2017, this study explores in depth the impact and heterogeneity characteristics of green finance pilot policies on carbon emissions from energy consumption at the macro level. It is found that the green finance pilot policy shows a sustained and significant inhibiting effect on the carbon emission intensity of energy consumption in the pilot provinces, and after the implementation of the policy, the marginal decline in carbon emission

intensity in the pilot area gradually expands with the advancement of the policy, which strongly verifies the effectiveness of the green finance policy in driving the low-carbon transition and responding to the governance of climate change, and highlights its practical value as a systematic tool for green development. In terms of the mechanism, the policy achieves carbon emission reduction through a dual path: on the one hand, it optimizes resource allocation, guides financial capital to gather in the fields of green industry and low-carbon technology, squeezes the financing space of high-carbon energy projects, and promotes the energy consumption structure to tilt towards clean energy; on the other hand, it drives financial innovation, incentivizes financial institutions to develop new tools such as green bonds and carbon financial derivatives, and broadens the channels of investment and financing for green projects, thus reducing the funding threshold for commercialization of low-carbon technologies. Reduce the financial threshold for commercialization of low-carbon technologies, and accelerate the green transformation process of energy-consuming industries. At the same time, there is regional differentiation in the emission reduction effect of green financial policies. The marginal contribution of policies is more prominent in the central and western regions due to the urgent demand for industrial structural adjustment and the large space for marginal improvement of green financial infrastructure; and the policy effect is relatively flat in the eastern region due to the path-locking effect of low-carbon technologies and the influence of diminishing marginal efficiency of financial resource allocation, which provides empirical evidence for the precise and differentiated design of policies.

Based on the above conclusions, in order to further unleash the systemic effectiveness of green financial policies in the process of the "dual-carbon" goal, it is necessary to promote policy optimization in two ways. One is to promote the iterative upgrading of the policy coverage and assessment system, and based on regional heterogeneity, extend the green finance pilot program in batches to the central and western energy-consuming industrial agglomeration zones and the eastern low-carbon technological innovation zones, so as to expand the spatial coverage of carbon emission reduction by means of the policy diffusion effect; at the same time, build a three-dimensional assessment index that includes the elasticity coefficient of carbon intensity, the efficiency of resource allocation in green finance, and the progress of transformation of energy-consuming industries. At the same time, a three-dimensional assessment index system containing the elasticity coefficient of carbon emission intensity, the efficiency of green financial resources allocation, and the progress of transformation of energy-consuming industries has been constructed, and a third-party assessment organization has been introduced to carry out a full-cycle monitoring to dynamically adjust the policy parameters in conjunction with the assessment results, so as to ensure synergy between emission reduction targets and policy tools. Second, promote financial innovation and industrial policy synergy and coupling, encourage financial institutions to develop climate-friendly financial products, such as green credit based on carbon footprint accounting, linked to the emission reduction performance of carbon asset pledge financing tools, to reduce the risk premium and financing costs of green projects; to strengthen the synergy and linkage of green financial policies with energy price mechanisms and environmental regulatory policies, and through the "Green Finance Strengthen the synergy between green financial policies and energy pricing mechanisms and environmental regulatory policies, and accelerate the iterative upgrading of the green industrial structure through the combination of "green financial subsidies + energy consumption ladder tariffs + energy-consuming industry carbon quota constraints" to form a policy network covering the entire chain of energy production, consumption and emission reduction.

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