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Green Finance Lens: How Sustainable Finance Boosts Energy Efficiency

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Abstract

This study investigates the relationship between green finance and energy efficiency using panel data from 276 Chinese prefecture-level cities over the period 2006–2021. Employing a two-way fixed effects model and robustness checks including Tobit regression, propensity score matching, and lagged dependent variable approaches, we find that green finance significantly enhances energy efficiency. The positive effect is particularly pronounced in cities with higher levels of financial development. Mechanism analysis reveals that green finance promotes energy efficiency primarily through two channels: increasing market openness and accelerating industrial structure upgrading. Based on these findings, we recommend strengthening institutional support for green finance, leveraging regional financial advantages, deepening market reforms, and promoting industrial transformation to enhance energy efficiency and support sustainable development goals.

Keywords: Green finance; energy efficiency; market openness; industrial structure

JEL Classification Q43; Q56; L51; F15

1. Introduction

Amid escalating global climate challenges and worsening environmental deterioration, sustainable development has emerged as a focal point of international concern. According to the United Nations' *2030 Agenda for Sustainable Development* and the *Paris Agreement*, countries worldwide are striving to achieve sustainability goals by reducing carbon

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emissions, improving resource efficiency, and advancing green transformation (Liu *et al*., 2025). Energy efficiency, as a key factor in attaining these objectives, serves an important function in reducing energy consumption and environmental pollution while fostering a transition in economic growth models and promoting a low-carbon, green society. Research by the International Energy Agency (IEA) indicates that improvements in energy efficiency could contribute to over 40% of global carbon emissions reduction targets while generating substantial economic benefits for the global economy. Facing the growing threats of global climate change and accelerating ecological decline. By directing capital flows toward environmentally friendly, energy-efficient, and clean energy projects, green finance provides the necessary financial support, lowers project financing costs, and enhances project feasibility and attractiveness (Hua *et al*., 2024). For example, the European Union's *Sustainable Finance Action Plan* has introduced regulatory frameworks and policy measures to support green finance growth. Moreover, the worldwide proliferation of financial instruments such as green bonds, sustainable credit, and environmentally-focused investment funds has reinforced the linkage between green finance and energy efficiency.

The synergistic development mechanism between green finance and energy efficiency has become a focal point in both academic research and policy discussions. From a theoretical perspective, the green financial system leverages innovative financial instruments and service models to provide diversified financing channels and risk management solutions for energy efficiency projects. This not only reduces the funding costs associated with such projects but also significantly enhances their investment attractiveness. At the same time, improvements in energy efficiency generate substantial economic returns and environmental benefits, thereby strengthening firms' market competitiveness. In turn, this positive feedback loop supports the innovation of green financial products and enhances risk management capabilities, forming a key driving mechanism for the transition toward a greener economy. However, existing research has predominantly focused on macro-level analyses at the national or provincial level, with relatively limited exploration of city-level microeconomic perspectives. Specifically, the mechanisms through which green finance impacts energy efficiency, along with regional differences in these effects, have not been extensively explored. This research gap not only hinders the development of a comprehensive theoretical framework but also constrains the precision of local green finance policy implementation. Accordingly, this study utilizes prefecture-level cities in China as the analytical framework to comprehensively explore the channels through which green finance influences energy efficiency. Furthermore, it incorporates regional development dynamics to formulate specific policy recommendations.

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This study examines how green finance influences energy efficiency within the framework of sustainable finance. First, this study reviews relevant theories and literature on green finance and energy efficiency, exploring the fundamental mechanisms and pathways through which green finance influences energy use effectiveness. Utilizing empirical data, it then assesses the impact of green finance on enhancing energy efficiency. Finally, the paper outlines policy suggestions aimed at strengthening the contribution of green finance to energy optimization, providing both theoretical foundations and actionable strategies to facilitate sustainable development goals. The study results show that the progress of green finance effectively boosts regional energy efficiency, with a stronger impact observed in cities with more developed financial systems. The examination of key mechanisms reveals that green finance promotes energy efficiency by expanding market openness and accelerating industrial transformation. This research not only strengthens the theoretical foundation of green finance and energy efficiency but also offers empirical support for developing region-specific green financial strategies, providing meaningful perspectives to accelerate the economy's transition toward sustainability.

2. Hypothesis Development

2.1 Green finance development and energy efficiency

As an emerging financial model, green finance primarily aims to achieve environmental sustainability goals through financial mechanisms (La Torre *et al*., 2024). In recent years, a wealth of research has investigated how green finance contributes to energy efficiency improvement from multiple angles. Hu and Gan (2025) conducted an in-depth analysis of the origins, motivations, and challenges of green finance, highlighting its significance in addressing environmental challenges and promoting sustainable development. Building on this foundation, (Ren *et al*., 2023)integrated innovative financial technology tools—such as blockchain, big data, and artificial intelligence – into green finance, offering new approaches to advancing environmental sustainability. These studies not only emphasize the innovation potential of green finance but also demonstrate its multidimensional role in achieving environmental goals. Regarding the global impact of green finance, Babic (2024) systematically analyzed key players, financial instruments, and political dynamics, affirming its crucial role in the global energy transition. Within the Chinese context, scholars have paid significant attention to the role of green finance in energy efficiency. Zhao *et al*. (2024) conducted an empirical analysis using Chinese data and discovered that green finance serves as a key factor in lowering corporate carbon emission intensity, offering robust evidence of its environmental advantages at the firm level. Additionally, Wang and Wang (2022) linked green

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finance with energy efficiency, revealing significant regional variations in its effectiveness. Further, Du *et al*. (2023) investigated the pathways through which green finance contributes to energy efficiency, highlighting its role in expanding the weighting of renewable energy within the overall energy structure, thereby enhancing energy use efficiency. Within the framework of international collaboration, Tu *et al*. (2021) analyzed the significance of green finance in China's Belt and Road Initiative (BRI). They asserted that beyond providing financial support, green finance acts as a crucial catalyst for advancing energy efficiency and sustainable development through strategic policy measures and market-driven reforms.

From a theoretical perspective, the implications of green finance on energy efficiency operates through several fundamental mechanisms. First, according to resource allocation theory, green finance enhances capital flow and optimizes resource distribution by shifting financial investments from high-emission, energy-intensive sectors to low-carbon and renewable energy projects. This process promotes industrial upgrading and enhances energy resource allocation, ultimately improving energy efficiency and reducing energy waste. Second, green finance is essential in supporting corporate technological progress, encouraging firms to adopt energy-efficient technologies. Such innovations not only contribute to carbon emission reductions but also enhance overall energy efficiency at the firm level. Furthermore, the implementation of green finance policies leverages both market mechanisms and government regulations to complement traditional policy measures, effectively driving energy conservation and efficiency improvements. In light of the earlier findings, the hypothesis below is presented:

H_1*: *The development of green finance significantly enhances energy efficiency.

2.2 Green finance development, market openness, and energy efficiency

Market openness is a broad economic concept that evaluates the degree of a country or region's integration into the global economy through trade, financial markets, and capital movements (Cerdeiro and Komaromi, 2021). Its level has profound implications for economic development, resource allocation efficiency, technological innovation, and international competitiveness (Lee and Chou, 2018). For instance, Ji and Zang (2021) found that higher market openness facilitates international trade and investment, enabling the adoption of advanced technologies and managerial expertise, which in turn enhances economic efficiency and innovation capacity. In the capital markets, increased openness attracts greater capital inflows and more sophisticated investors, thereby improving market liquidity and price discovery functions, ultimately contributing to stock market stability. Thus, market

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openness drives efficient economic growth while simultaneously boosting regional competitiveness and sustainable development through enhanced resource allocation and the stimulation of technological advancements (Yuan, 2024).

Market openness serves as a key intermediary in the relationship between green finance and energy efficiency. The expansion of green finance promotes the adoption of advanced international financial technologies and management strategies, improves resource allocation, and accelerates the globalization and specialization of the green financial sector, ultimately leading to greater market openness (He *et al*., 2024). As market openness expands, more international green capital flows into the economy, providing financial support for clean energy projects and green technology innovation. At the same time, a liberalized market environment fosters innovation and facilitates knowledge diffusion, encouraging firms to allocate resources to the innovation and development of energy-saving and emission-reducing technologies, thereby improving overall energy efficiency (Tiwari *et al*., 2025). Extending the previous analysis, the following hypothesis is established:

H_2*: *Green finance promotes energy efficiency by enhancing market openness.

2.3 Green finance development, industrial structure, and energy efficiency

Industrial structure describes the relative composition and linkages of various sectors within a country or region, expressing the stage of economic expansion and the efficiency of resource coordination. The ongoing transformation of industrial structure plays a vital role in fostering regional economic progress, particularly within the framework of economic shifts and sustainable development, where its impact on green finance and energy efficiency has become a focal point of research (Gaies *et al*., 2020).Such as, Jiang and Wu (2023) utilizing cross-national panel data from developing countries, the study investigated the linkage between financial market evolution and industrial structure, revealing a statistically significant positive association between the advancement of the banking sector and industrial upgrading. Furthermore, as an effective tool for promoting green economic growth and structural transformation, green finance acts as a pivotal force in facilitating industrial upgrading by directing financial resources toward high-value-added, low-energy-consumption industries.

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3. Variable Selection

3.1 Variable definition

Table 1 presents the study variables with corresponding methodological specifications.

Table 1: Variable definitions

Variable category	Name	Symbol	Definition
Dependent variable	Energy efficiency	*EE*	Calculated using the super-efficiency SBM model
Independent variable	Green finance	*GF*	Green finance index
Mediating variables	Market openness	*MO*	Ln (actual utilized foreign investment)
	Industrial structure	*CS*	Service and manufacturing output share
Control variables	Foreign investment level	*FIL*	Actual utilized foreign investment / GDP
	Urbanization level	*LOU*	Urban permanent population / total permanent population
	Government intervention	*DGI*	General government fiscal expenditure / GDP
	Population density	*PD*	Permanent population / urban area
	Marketization level	*ML*	Ln (urban private and self-employed workers / urban employed population)
	Employment structure	*ES*	Number of employees in the tertiary industry / total employment
	Infrastructure level	*IL*	Per capita road freight volume

Source: Authors´own elaboration

In summary, the evolution of industrial structure not only directly influences regional economic efficiency but also affects energy efficiency and sustainable development through its integration with green finance. On the one hand, green finance facilitates industrial transformation by implementing differentiated credit policies and investment guidance, encouraging the transition of high-energy-consuming and high-pollution industries while supporting the development of emerging sectors such as renewable energy and environmental protection (Naseer *et al*., 2025). This structural adjustment reduces economic dependence on energy-intensive industries and promotes the adoption of more efficient energy utilization technologies and management models, thereby enhancing overall energy efficiency.

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For example, green finance supports technological upgrades in traditional manufacturing industries, helping them reduce energy resource consumption per unit of production and improve production efficiency. On the other hand, industrial upgrading itself creates favorable conditions for energy efficiency improvements. As the industrial structure shifts toward higher value-added, smarter, and greener sectors, the share of high-tech industries and service sectors increases. These industries typically exhibit higher energy efficiency and lower energy intensity, reinforcing the positive impact of industrial restructuring on energy utilization. Thus, industrial transformation not only mirrors the efficacy of green finance but also acts as a pivotal catalyst for enhancing energy efficiency. Based on the aforementioned analysis, the subsequent hypothesis is advanced:

H_3*: *Green finance enhances energy efficiency by optimizing industrial structure.

Dependent variable

Energy efficiency (*EE*): Energy efficiency is defined as the optimization of energy utilization in production or consumption processes to maximize output while minimizing energy input. It is commonly measured in terms of the economic benefits, production efficiency, or service value generated per unit of energy consumption (Murshed *et al*., 2023). This research relies on green total factor energy efficiency to quantify energy efficiency. Under this framework, the assessment of energy efficiency not only focuses on economic benefits but also incorporates environmental impacts. To comprehensively evaluate the overall efficiency of regional economies in the context of sustainable development, this study implements the super-efficiency Slack-Based Measure (SBM) model for assessing energy efficiency at the regional level (Lu *et al*., 2012). The model accounts for both desirable and undesirable outputs, offering a more precise evaluation of energy efficiency performance. The detailed structure of the SBM model, which includes undesirable outputs, is presented as follows:

$$minEE_k = \left. 1 - \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{ik}} \right/ 1 + \frac{1}{m_{g+}+m_b}\left(\sum_{t=1}^{m_g}\frac{S_t^g}{y_{tk}^g} + \sum_{j=1}^{m_b}\frac{S_j^b}{y_{jk}^b}\right) \tag{1}$$

$$\text{s.t.} \quad \begin{aligned} &\sum_{p=1}^{n}\lambda_p x_{ip} + S_i^- = x_{ik}, i = 1, \dots, m \\ &\sum_{p=1}^{n}\lambda_p y_{tp}^g + S_i^g = y_{tk}^g, t = 1, \dots, m \\ &\sum_{p=1}^{n}\lambda_p y_{jp}^b + S_i^b = y_{jk}^b, j = 1, \dots, m \end{aligned} \tag{2}$$

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Equation (1) represents the objective function, where EE_κ denotes the minimized target value, corresponding to the energy efficiency of the κ-th decision-making unit (DMU). m represents the number of input variables, while m_g and m_b denote the number of desirable and undesirable output variables, respectively. x_{ik} refers to the value of the i-th input variable for the k-th DMU. The slack variables S_i^-, S_t^g, and S_j^b indicate the potential improvements in inputs, desirable outputs, and undesirable outputs, respectively. n represents the total number of samples. Equation (2) defines the constraint conditions of the model, ensuring the feasibility of the optimization process while considering both desirable and undesirable outputs.

Independent variable

Green finance (*GF*): Green finance refers leveraging innovative financial tools and market-based mechanisms to direct capital toward economic activities that support environmental preservation, resource efficiency, climate regulation, and sustainable development. Its core aim is to balance economic expansion with ecological protection, accelerating the move toward a low-carbon economy and nurturing a more environmentally sustainable economic system. Based on the definition of green finance and following the methodologies of Wang *et al*. (2024) and Wang and Fan (2023), this study selects seven key indicators to measure green finance. Details on the measurement of specific indicators are presented in Table 2.

Table 2: Green finance indicator system

Primary indicator	Secondary indicator	Tertiary indicator	Indicator description
Green finance development level	Green credit	Eco-project loan share	Eco-loans / Total loans
	Green investment	Pollution control investment ratio	Pollution investment / GDP
	Green insurance	Enviro-liability insurance uptake	Enviro-premiums / Total premiums
	Green bonds	Green bond market share	Green bonds issued / Total bonds issued
	Green support	Environmental budg*et a*llocation	Enviro-expenditure / Total budget
	Green funds	Green fund market presence	Green fund AUM / Total fund AUM
	Green equity	Carbon/energy trading activity	(Carbon + energy + emission trades) / Total equity trades

Source: Authors´ own elaboration

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Mediating variable

Market openness (*MO*): Market openness denotes the extent to which a nation or region engages with the global economy through the facilitation of foreign capital inflows and the establishment of robust economic connections. In this study, market openness is represented by the logarithmic transformation of realized foreign investment. Specifically, the scale of utilized foreign investment serves as an indicator of a region's ability to draw in overseas capital. A higher level of market openness not only indicates greater attractiveness in global capital flows but also facilitates the introduction of advanced green technologies and management practices through foreign investment. This, in turn, strengthens the positive impact of green finance on energy efficiency (Rahman *et al*., 2023).

Industrial structure (*CS*): Industrial structure refers to the relative scale and interconnections among different industrial sectors within a region. Adopting the methodology established by Xue *et al*. (2024), this study quantifies industrial structure by calculating the ratio of the total added value of the secondary and tertiary sectors relative to regional GDP. This ratio reflects the ratio of high-value-added industries (such as the tertiary sector) and traditional industries (such as the secondary sector) in the regional economy, indicating the degree of economic structural optimization and industrial upgrading trends. The transition toward a more advanced industrial structure facilitates the reallocation of resources from high-energy-consuming, high-pollution traditional industries to low-carbon and green industries, thereby enhancing energy efficiency.

Control variables

To improve the accuracy of the empirical analysis, this study incorporates seven control variables: foreign investment level (*FIL*), urbanization level (*LOU*), government intervention (*DGI*), population density (*PD*), marketization level (*ML*), employment structure (*ES*), and infrastructure level (*IL*). These variables contribute to controlling potential interfering elements that might distort the association between green finance and energy efficiency(Wang and Wang, 2024).

3.2 Data sources

This study constructs a panel dataset covering 276 prefecture-level cities in China from 2006 to 2021. *EE* data and control variables are obtained from the *China Urban Statistical Yearbook*. *GF* data are primarily sourced from multiple authoritative publications, including the *China Science and Technology Statistical Yearbook*, *China Energy Statistical Yearbook*,

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China Financial Yearbook, *China Agricultural Statistical Yearbook*, *China Industrial Statistical Yearbook*, and *China Tertiary Industry Statistical Yearbook*, as well as official websites of institutions such as the People's Bank of China. Prior to analysis, the data were pre-processed: indicators with severe missingness were dropped and continuous variables were winsorized, yielding a final sample of 4,282 observations.

3.3 Variable measurement

Table 3 provides an overview of the descriptive statistics for the key variables. The findings demonstrate that *EE* exhibits a certain degree of dispersion, with a moderate mean value and a noticeable range of fluctuations. Similarly, *GF* also has a moderate mean, but its variation is relatively smaller, suggesting a more concentrated distribution within the sample. In contrast, *MO* shows a higher mean and a broader fluctuation range, indicating significant differences in market openness across samples. Additionally, *CS* has a mean value close to 1, suggesting a relatively uniform distribution, though some degree of dispersion remains.

Table 3: Summary statistics

VarName	Obs	Mean	SD	Min	Median	Max
EE	4282	0.3196	0.1258	0.1348	0.2952	1.0053
GF	4282	0.3159	0.1086	0.0721	0.3226	0.6366
MO	4282	11.7364	1.9146	6.4986	11.7897	15.7537
CS	4282	0.8720	0.0812	0.5011	0.8832	0.9997
FIL	4282	0.0181	0.0182	0.0000	0.0120	0.0869
LOU	4282	0.5282	0.1625	0.1898	0.5108	0.9463
DGI	4282	0.1803	0.0869	0.0636	0.1580	0.5365
PD	4282	5.7766	0.8790	2.8893	5.9406	7.2545
ML	4282	−0.0201	0.6414	−1.6809	−0.0323	1.6490
ES	4282	0.5476	0.1390	0.0991	0.5452	0.9999
IL	4282	25.2683	19.4235	3.3968	20.5908	120.7202

Source: Authors´own elaboration

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4. Hypothesis Testing

4.1 Hypothesis 1 testing

Hypothesis 1 is tested using a two-way fixed effects model (Zhang *et al*., 2024). The model specification is given in Equation (3), where EE_{it} represents the energy efficiency of region i in year t, CF_{it} denotes the green finance level of region i in year t, and $\sum_{i=1}^{n} \alpha_i Controls$ is a vector of control variables. μ_i and γ_t capture the region-fixed and time-fixed effects, respectively, while ε_{it} represents the exogenous disturbance term.

$$EE_{it} = \alpha_0 + \alpha_1 GF_{it} + \sum_{i=1}^{n} \alpha_i Controls + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

Table 4 reports the empirical findings concerning the relationship between *GF* and *EE*. Column (1) displays the regression outcomes in the absence of control variables, showing that *GF* has a positive and statistically significant effect on *EE* at the 5% level. Column (2) includes control variables but does not account for region- and time-fixed effects, and the positive effect of *GF* remains significant, providing initial support for Hypothesis 1. Column (3) incorporates both region- and time-fixed effects based on Column (2), and the regression results indicate that green finance exerts a statistically significant positive impact on energy efficiency at the 1% level. Specifically, a one-standard-deviation increase in green finance development is associated with approximately 1.49% improvement in energy efficiency, demonstrating that green financial policies effectively enhance regional energy utilization efficiency. Additionally, green finance supports technological innovation, particularly by providing financial incentives for high-energy-consuming firms to undergo technological upgrades and increase RandD investment. These mechanisms further drive improvements in regional energy efficiency, providing robust empirical support for Hypothesis 1.

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Table 4: Baseline regression results

	(1)	(2)	(3)
	EE	***EE***	***EE***
GF	0.1116** (2.1384)	0.2830*** (15.9898)	0.1374*** (2.5832)
FIL		−0.4529*** (−4.4351)	−0.2128 (−1.1558)
LOU		0.1437*** (11.0283)	−0.0110 (−0.2703)
DGI		−0.2850*** (−11.5651)	−0.2486*** (−4.5512)
PD		0.0014 (0.5803)	−0.0633*** (−4.1268)
ML		0.0306*** (10.5771)	0.0049** (1.9864)
ES		0.1321*** (8.8720)	0.1829*** (7.2594)
IL		−0.0004*** (−3.9045)	−0.0003*** (−4.1929)
_cons	0.2843*** (17.2415)	0.1437*** (7.5607)	0.6051*** (6.8555)
City FE	Yes	No	Yes
Year FE	Yes	No	Yes
N	4282	4282	4282
Adj. R^2	0.6641	0.2073	0.6792

Note: *** indicates a significance level of $P < 0.01$, ** indicates $P < 0.05$, and * represents $P < 0.1$. The *t*-values are presented in parentheses. *FE* stands for fixed effects The same applies to the following table.

Source: Authors´own elaboration

4.2 Robustness tests of hypothesis 1

To validate the reliability of the baseline regression results, this study utilizes various verification approaches (Wang *et al*., 2023). First, the Tobit model is used as an alternative estimation method to re-examine the connection between *GF* and *EE*. Second, the dimension

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of fixed effects is adjusted from the regional level to the provincial level to test the sensitivity of the model results to different control variable settings. Additionally, in consideration of the unique economic development levels and policy environments of China's four directly governed municipalities – Beijing, Shanghai, Tianjin, and Chongqing – these cities are excluded from the sample to mitigate the potential influence of administrative divisions on the regression results. Columns (1) to (3) of Table 5 present the robustness test results. The outcomes across all three methods are positive and statistically significant, strengthening confidence in the baseline regression results. These outcomes provide further empirical support for Hypothesis 1.

Table 5: Robustness tests

	1	2	3
	Tobit model	**Alternative fixed effects**	**Sample exclusion**
	EE	***EE***	***EE***
GF	0.1374*** (2.9657)	0.2618*** (3.6740)	0.1947*** (3.3124)
_cons	0.5568*** (7.0014)	0.1756*** (3.8613)	0.5981*** (7.0503)
Controls	Yes	Yes	Yes
City FE	Yes	No	Yes
Year FE	Yes	Yes	Yes
Province FE	No	Yes	No
N	4282	4282	4218
Adj. R^2		0.4013	0.6819

Source: Authors´own elaboration

To mitigate self-selection concerns, this study employs propensity-score matching (PSM). PSM simulates a randomized experiment and thereby reduces estimation error stemming from sample-selection bias. By calculating each unit's propensity to receive the treatment and then matching treated and control observations on this score, the procedure balances observable characteristics across groups and neutralizes the distorting influence of selection bias on the findings. Because endogeneity often threatens empirical validity, we

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complement PSM with a lagged-dependent-variable specification that tackles simultaneity or reverse feedback between regressors and the outcome. Including the lagged outcome absorbs part of the endogeneity, yielding cleaner estimates. As reported in Table 6, both approaches produce a significant positive coefficient that aligns with the baseline regression, underscoring the robustness of our results. The documented causal link is therefore not an artefact of model mis-specification or endogeneity; it is statistically reliable and lends additional support to Hypothesis 1.

Table 6: Endogeneity test

	1	2	3
	PSM	**Dependent variable lagged by one period**	**Dependent variable lagged by two periods**
	EE	***L.EE***	***L2.EE***
GF	0.1968*** (3.5141)	0.1121** (2.2662)	0.1258*** (2.9562)
_cons	0.8606*** (9.4498)	0.4703*** (17.3026)	0.4013*** (12.3834)
Controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	3237	4017	3751
Adj. R^2	0.6794	0.6884	0.7105

Source: Authors´own elaboration

4.3 Extended analysis of hypothesis 1

The degree of financial development significantly influences the effectiveness of green finance and improvements in energy efficiency. In this study, financial development is measured by the ratio of year-end deposit and loan balances of financial institutions to regional GDP. Using the median value as a threshold, the sample is categorized into cities with lower and higher levels of financial development. In cities with more advanced financial development, financial institutions are more mature, and financial markets are more developed,

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providing a greater pool of capital and more efficient financial services for green finance projects. This environment facilitates a more effective enhancement of *EE*. Conversely, in regions with weaker financial growth, the implementation of *GF* may face challenges such as capital shortages and a lack of financial instruments, which could weaken its influence on *EE* improvements. The regression results in Table 7, Columns (1) and (2), support this analysis, showing that the positive impact of green finance on energy efficiency is stronger in cities with a higher degree of financial development.

Table 7: Heterogeneity analysis

	1	2
	Financially underdeveloped	**Financially developed**
	EE	***EE***
GF	−0.0295 (−0.4651)	0.2504*** (2.7046)
_cons	0.9468*** (12.0543)	0.5014*** (4.0460)
Controls	Yes	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
N	2141	2141
Adj. R^2	0.7516	0.6885
Fisher combined test *p*-values	0.0060	

Source: Authors´own elaboration

4.4 Hypothesis 2 testing

Hypothesis 2 is tested by extending Equation (3) with the inclusion of *MO*, which MO_{it} represents the market openness level of region *i* in year *t*. The verification process follows Equations (3) and (4) to examine the mediating effect of *MO* in the relationship between *GF* and *EE*. Table 8 presents the estimated results of the regression model.

$$EE_{it} = \beta_0 + \beta_1 GF_{it} + \beta_2 MO_{it} + \sum_{i=1}^{n} \beta_i Controls + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

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MO reflects the degree of marketization and resource allocation efficiency within a region and serves as a crucial indicator of economic dynamism and competitiveness. The development of *GF* promotes the internationalization and specialization of the green financial market, thereby increasing market openness. Additionally, the inflow of international green capital provides financial support for clean energy projects and green technology innovation, ultimately enhancing *EE* (Bhattacharyya, 2022). Columns (1) and (2) of Table 8 present the mediation effect test results for *MO*. Column (1) shows that *GF* has a significantly active influence on *EE*. In Column (2), *MO* is introduced as a mediating variable, and the regression results indicate that after including *MO*, the coefficient of *GF* on *EE* decreases but remains significantly positive. This suggests that *MO* plays a partial mediating role in the active influence of *GF* on *EE*. In other words, *GF* not only directly enhances *EE* but also promotes *EE* indirectly by improving *MO*, thereby providing empirical support for Hypothesis 2.

4.5 Hypothesis 3 testing

Following the approach used for Hypothesis 2, Hypothesis 3 is tested by extending Equation (3) with the inclusion of *CS*, which CS_{it} denotes the industrial structure of region *i* in year *t.* The verification process follows Equations (3) and (5) to examine the mediating effect of industrial structure in the relationship between *GF* and *EE*. The regression analysis results of the model are reported in Table 8.

$$EE_{it} = \pi_0 + \pi_1 GF_{it} + \pi_2 CS_{it} + \sum_{i=1}^{n} \pi_i Controls + \mu_i + \gamma_t + \varepsilon_{it} \tag{5}$$

The role of *GF* in enhancing *EE* extends beyond direct capital allocation; it also operates through *CS* adjustments as a key mediating mechanism. *CS* is one of the core determinants of *EE*, as its optimization and upgrading fundamentally reshape energy utilization patterns and efficiency levels. *GF* promotes this shift by channeling financial resources into low-carbon and eco-friendly sectors, hastening industrial restructuring and optimization, and consequently enhancing *EE* indirectly(Chang *et al*., 2025). Columns (1) and (3) of Table 8 present the mediation effect test results for *CS*. After including *CS*, the coefficient of *GF* on *EE* changes while remaining significantly positive. These results suggest a partially mediated relationship, where *CS* indirectly affects the *GF-EE* association, providing empirical support for Hypothesis 3.

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Table 8: Mediating effect

	(1)	(2)	(3)
	EE	**EE**	**EE**
GF	0.1374*** (2.5832)	0.1319** (2.4605)	0.1486*** (2.8138)
MO		0.0117*** (6.0999)	
CS			0.1784** (2.0095)
_cons	0.6051*** (6.8555)	0.4788*** (5.7245)	0.4472*** (3.5147)
Controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	4282	4282	4282
Adj. R^2	0.6792	0.6822	0.6799

Source: Authors´own elaboration

5. Conclusion

5.1 Findings and policy recommendations

This study conducts an empirical analysis of the connection between *GF* and *EE* using data from Chinese prefecture-level cities, yielding the following key findings: First, *GF* is significantly and positively correlated with regional *EE*. Moreover, this positive effect is more pronounced in financially developed cities, where the financial system is more mature and capable of providing better financial support for green projects. Second, mechanism tests reveal that *GF* enhances *EE* through two primary channels: increasing market openness and promoting industrial structure optimization. By attracting international green capital and facilitating the transition to a low-carbon economic structure, *GF* indirectly contributes to improving *EE*. Based on these conclusions, this study proposes the following policy recommendations:

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First, strengthen the policy framework and institutional support. Government authorities should focus on refining the regulatory framework for green finance by establishing standardized industry norms and leveraging a diversified set of policy instruments. These may include fiscal incentives, tax relief policies, and risk-sharing mechanisms to stimulate financial institutions' proactive engagement in green investments. Furthermore, enhancing the oversight and monitoring mechanisms for fund allocation is crucial to ensuring capital efficiency and preventing resource misallocation. In particular, strengthening green credit policies can encourage banking institutions to allocate more financial resources to green industries. Additionally, a well-structured green bond issuance system should be developed to enable qualified enterprises to access green financing channels. Moreover, comprehensive green insurance mechanisms should be established to mitigate financial risks associated with green projects, thereby enhancing investment attractiveness and stability. Second, leverage regional advantages for green finance demonstration and expansion. Regions with well-developed financial systems should harness their resource advantages to pioneer innovative green finance models. For instance, the establishment of green finance pilot zones and carbon finance demonstration projects offers transferable policy models for regional adoption. In addition, regional cooperation mechanisms should be strengthened to facilitate cross-border financial collaboration, enabling the efficient pooling and sharing of resources. Establishing an integrated regional green finance network will also allow for better synergy, enhancing the complementary strengths of different areas and promoting balanced, sustainable development. Third, deepen financial market reforms to expand green investment channels. A well-functioning green financial system requires an inclusive and dynamic financial market. To this end, the government should attract greater participation from private capital and foreign financial institutions by lowering entry barriers and optimizing the business environment. Enhancing connectivity between regional financial markets and promoting financial integration will improve capital efficiency and ensure the effective implementation of green finance strategies. This includes upgrading green financial infrastructure, developing comprehensive financial information-sharing platforms, and fostering innovation in green financial products. Additionally, a diverse range of financial instruments should be developed to meet various financing needs. Strengthening international collaboration in green finance is also essential to positioning domestic green financial markets within the global landscape and contributing to international sustainable finance governance. Fourth, promote industrial transformation and technological upgrading. Green finance should play a pivotal role in driving industrial transformation by facilitating investment in clean energy, energy conservation, and low-carbon technologies. The government should intensify its support for green industries while guiding traditional industries toward decar-

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bonization and resource efficiency. Incentivizing enterprises to increase RandD investment in energy-saving and emissions-reducing technologies will accelerate industrial upgrading and enhance energy efficiency across high-consumption sectors. By fostering technological advancements, green finance can drive a structural shift towards a low-carbon economy while simultaneously improving overall economic productivity. Fifth, establish a collaborative governance mechanism for integrated development. To maximize the effectiveness of green financial policies, local governments should integrate green finance development with regional economic strategies, ensuring a coordinated approach across departments and sectors. A cross-agency coordination mechanism should be established to develop specialized action plans, set clear objectives, and define key policy measures. Efforts should also be made to implement a green finance performance evaluation system, incorporating green finance metrics into local government assessments to reinforce accountability. Furthermore, developing a specialized workforce by investing in green finance talent cultivation will provide long-term human capital support for the sector's growth. Public awareness campaigns should also be conducted to enhance societal recognition of green finance, fostering a culture of sustainable investment and responsible financial decision-making. Through these strategic initiatives, a comprehensive and well-integrated green financial policy framework can be established. This will not only enhance the synergy between green finance and sustainable industries but also facilitate a regionally coordinated transition towards a low-carbon economy, ultimately contributing to long-term economic resilience and environmental sustainability.

5.2 Discussion and limitations

This research investigates the theoretical relevance and practical applications of *GF* in improving *EE*. The findings provide important insights for local governments in formulating differentiated green finance policies, while also offering practical guidance for financial institutions to optimize green financial product design and improve capital allocation efficiency. Furthermore, the identification of *MO* and *CS* as key mediating mechanisms highlights the importance of external environment factors and internal structural adjustments in shaping the association between *GF* and *EE*. This provides a foundation for future research to explore multi-dimensional implementation pathways and external conditions that enhance the effectiveness of green finance policies.

Despite the progress made in this study, several limitations remain. First, the sample is limited to prefecture-level cities in China. While this approach effectively captures the characteristics of China's regional green finance development, the generalizability of the findings remains uncertain due to differences in institutional environments and development

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stages across countries. Further validation is needed in a broader international context. Second, this study primarily employs a static analytical framework, which may not fully capture the complex dynamic interactions between green finance and energy efficiency. In particular, under conditions of economic structural transformation or significant policy shifts, the mechanisms through which green finance influences energy efficiency may exhibit time-varying characteristics. To address these limitations, future research could consider expanding the sample scope to include a wider range of countries and regions, while incorporating dynamic analytical methods to enhance the explanatory power and applicability of the findings.

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